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Strongly correlated electron systems and quantum critical phenomena

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1. Introduction

Lately, there has been an upsurge of interest in what is known as quantum phase transitions, or quantum critical phenomena. Quantum phase transitions are observed in pure form only at $T = 0$, although their influence on the properties of matter may extend to the region of finite temperatures. Here, the ground quantum state of the system changes in a fundamental way. In view of the close relation between the static and dynamic properties of a quantum system, the temporal properties of such a system strongly affect its behavior in the critical region at $T = 0$, increasing the effective dimensionality of the system. In contrast to the classical case, the transition occurs not due to a change in temperature but due to a change in the parameters of the Hamiltonian. As examples we can mention the magnetic field in the case of the quantum Hall effect, doping in the case of high-T_c superconductors (HTSCs), and the strength of disorder in a conductor near the metal – insulator transition. The interest in quantum phase transitions is caused largely by the fact that many unusual properties of strongly correlated electron systems at low temperatures and of high-T_c superconductors can be explained by the proximity to the quantum critical point.

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The first seminar "Strongly correlated electron systems and quantum critical phenomena" was held on April 11, 2003 at the L F Vereshchagin Institute for High Pressure Physics (or IHPP) of the Russian Academy of Sciences (RAS), located in Troitsk, Moscow region. We believe this to have been an important event because no special conferences or seminars devoted exclusively to the physics of strongly correlated systems had been organized in the past in Russia; relevant problems of this kind were discussed at broader scientific gatherings, such as meetings devoted to low-temperature physics. A report on the proceedings of that seminar can be found in the April issue of *Phys. Usp.* **47** 401 (2004). With the support of the Presidium of the RAS, on June 11, 2004, the second workshop "Strongly correlated electron systems and quantum critical phenomena" was again held at IHPP. Note that, compared to the 2003 seminar, the number of reports more than doubled and amounted to 23 oral reports and 19 poster reports. The *Program Committee* of this seminar include L V Keldysh (Chairman, P N Lebedev Physics Institute, or FIAN, RAS), P I Arseev (FIAN), S V Demishev (A M Prokhorov General Physics Institute, or GPI, RAS), S M Stishov (IHPP), V B Timofeev (Institute of Solid State Physics, or ISSP, RAS), and L A Fal'kovskii (L D Landau Institute of Theoretical Physics, or ITP, RAS). The *Organizing Committee* consisted of Stishov (Chairman, IHPP), Arseev (FIAN), V V Brazhkin (IHPP), T V Valyanskaya (IHPP), Demishev (GPI), V A Zayats (Division of Physical Sciences, RAS), V N Ryzhov (IHPP), and L B Solodukhina (IHPP).

The seminar was organized around three thematic sections: "Strongly correlated electrons and superconductivity", "Quantum critical phenomena and magnetic properties", and "Strongly correlated systems of different nature". There was also a poster section. A brief summary of the reports presented in these sections is given below.

2. Strongly correlated electrons and superconductivity

This section combined the reports devoted primarily to the various correlation effects in superconductors and to the competition between various types of ordering caused by electron – electron interactions.

Yu N Ovchinnikov and A A Varlamov (both from ITP) in their report "Strong vortex – antivortex fluctuations in type II

superconductor films'' showed that it is important to take correlations in superconductors into account not only on the microscopic level. Even for such seemingly well-studied systems as superconducting films, it was found that vortex – antivortex correlations may play a significant role. What is interesting in this result is that it differs from the ordinary ideas according to which only long-wave fluctuations with a small deviation in the order parameter from the average value are important near the superconducting transition point. The researchers showed that near the phase transition point there is a broad range of temperatures within which the predominant fluctuation contribution is related to the production of small-sized vortex – antivortex pairs. They determined the parameters of the superconducting film and the temperature interval for which the contribution to the specific heat, provided by fluctuation production of such vortex pairs, is much larger than the contribution from long-wave modes.

A closely related report ''Neutron diffraction by vortex lattices in thin high-T_c superconducting films'' was made by V L Aksenov (Joint Institute for Nuclear Research, or JINR). The report covered the results of studying the transitions in vortex structures in thin superconducting films. The case where the field is applied perpendicular to the film has been studied most thoroughly. The situation proved to be more complex when the field was parallel to the film: the strength of the first critical field is much larger than when the field is perpendicular to the film, and direct visualization becomes almost impossible. In view of this, the neutron diffraction method becomes greatly important as a direct method for visualizing the vortex configuration and for measuring the vortex – vortex separation. The researchers were the first to experiment with thin (2000, 2500, and 3000 Å) and ultrathin (800 Å) high-T_c superconducting $YBa_2Cu_3O_7$ films and used reflectometry and diffraction of polarized neutrons in a parallel magnetic field with a strength of up to 1.5 T. They found that at certain values of the magnetic field strength, in the vortex structure there occurs transitions into a new state, in which the number of vortex rows increases by one unit, i.e., vortex rows undergo discrete transformations. Their study also revealed that the vortex rows have a structure of nearly parallel lines. They corroborated the theoretically predicted discrete transformation of vortex rows and measured the vortex – vortex separation a. For instance, the measured distance $a = 445$ and 480 Å at $H = 11$ and 1.5 T, and the number of vortices in rows is four and five, respectively.

The general problem of the interaction of magnetic correlations and the superconductivity on the macroscopic level was discussed in the report by V V Ryazanov, V A Oboznov, V V Bol'ginov, and A K Feofanov (all from ISSP) named ''Electron correlations in Josephson junctions with a ferromagnetic''. The researchers investigated superconductor – ferromagnetic – superconductor (SFS) structures in which the proximity effect gives rise to nontrivial phenomena. Within a region of size on the order of the coherence length near the superconductor – ferromagnetic (SF) junction, the total momentum of the pairs in the ferromagnetic in the ground state is not zero, which leads to the appearance of an inhomogeneous, sign-changing superconducting order parameter. The physical reason for the spatial oscillations of the order parameter lies in the exchange splitting of the electron subbands with different directions of spins. In an SFS structure with a ferromagnetic interlayer of thickness d_F close to half the wavelength of the spatial oscillations, the signs of the order parameters on superconducting banks of the 'sandwich' are opposite, i.e., the phase difference of the superconducting wave function over the SFS junction in the absence of an external field and a current is π. Experimentally, the transition to the π-state can be identified by the appearance of an anomalous recursive temperature dependence of the critical current. The researchers studied in great detail the dependence of the critical current flowing through the Josephson SFS sandwich on the thickness of the ferromagnetic layer. The critical current behaves in a nonmonotonic fashion, vanishing at the points of transition to and from the π-state. The phase half-period shifts near the transition to the π-state were directly observed in various interference experiments. Thus, they discovered two transition points in the dependence of the critical current on the layer thickness: at thicknesses close to half the period of the spatial oscillations, and at thicknesses close to an integer period. The main results of the studies on the SF systems is the reliable confirmation of the presence of a peculiar superconducting state induced in the ferromagnetic near the boundary with the superconductor in multilayer SF structures.

G B Teitel'baum (Kazan' Physical-Technical Institute) and L P Gor'kov (ITP) presented the report ''The pseudogap mode and dynamic phase separation in high-temperature superconductors'', in which they discussed, on the microscopic level, how magnetic ordering affects superconductivity and vice versa. The experimental data suggest that there is a tendency to phase separation in superconducting metal oxides. The researchers found that the pseudogap behavior of nuclear spin relaxation in cuprates may be related to the dynamic phase separation into metallic and magnetic regions. Such separation is caused by an emerging (at temperatures much higher than T_c) first-order phase transition, whose extension to greater scales is disrupted because the electroneutrality of the CuO_2 planes is violated. The change in the relative volumes of the coexisting phases with different fluctuation frequencies, which moves the fluctuation spectrum away from the vicinity of the nuclear magnetic resonance (NMR) frequency, manifests itself as pseudogap suppression of the relaxation rate. The authors of the report discovered that, for a broad range of cuprates, at temperatures above T_c but below a certain temperature T^* the relaxation rate of the copper nuclei, $1/^{63}T_1$, is determined by two independent mechanisms: the relaxation on incommensurate 'stripe' excitations, which leads to a temperature-independent contribution, and the chaotic movements of the metallic and magnetic subphases, which lead to a 'universal' temperature-dependent contribution. They concluded that the stripe excitations are related to external doping and may be pinned by structural defects. In the case of LaSrCuO, their estimates agree quantitatively with the data gathered from inelastic neutron scattering for this compound.

The discussion about which pairing mechanism is predominant in high-T_c superconductors and to what extent the properties of high-T_c superconductors can be explained by the existing theories is far from being completed. While Teitel'baum and Gor'kov attempted to find an original explanation for some of the properties of high-T_c superconductors, E G Maksimov (FIAN) in his report ''How strong are electron correlations in high-T_c superconducting systems?'' was skeptical about the need to explain the properties of high-T_c superconductors by exotic mechanisms. By generalizing the results of a large number of experiments he showed that very many properties of super-

conducting cuprates are close to those of ordinary metals. The experimental data on the evolution of the electronic structure in high-T_c superconductors, from the antiferromagnetic Mott insulator to the overdoped superconductor, were presented, and possible theoretical explanations of the observed changes were discussed. Maksimov also found that the metal–insulator transition occurs in these systems at rather low doping levels, with the result that the superconducting phase cannot be considered a doped insulator. The carrier concentration in such a phase exceeds the level of formal doping, while the Fermi surface coincides with that calculated from first principles. Such coincidence is very unlikely for systems with a strong exchange-correlation effect. Moreover, calculations done within Eliashberg's theory relying on a real phonon spectrum testify that electron–phonon interaction in high-T_c superconductors plays, if not a decisive, then at least an important role in the formation of the properties observed in such compounds.

The report that followed, viz. "Coupled phonon–plasma modes and the problem of electron–phonon interaction", was delivered by L A Fal'kovskii (ITP). He suggested that the problem of describing the electron–phonon interaction contains controversial arguments in dealing not only with high-T_c superconductors but also with ordinary metals and doped semiconductors. The researcher studied the extent to which the electron–phonon interaction affects the phonon spectra of metals and doped semiconductors. He assumed that the renormalization of the speed of sound in metals, caused by electron–phonon interaction, has been calculated in a number of approaches incorrectly and that this has led to too strong phonon dispersion. In his approach, Fal'kovskii used the kinetic equation technique and also allowed for the Maxwell equations, since longitudinal optical oscillations generate an electric field. His analysis showed that the Coulomb interaction of carriers with longitudinal optical oscillation is most important, while deformation interaction plays a minor role (in view of the adiabaticity of the electron–phonon system) and affects both longitudinal and transverse modes to the same extent. Recently, there have been reports about the observation of coupled phonon–plasmon modes in the Raman scattering in gallium arsenide put in a strong magnetic field. When the sample is placed in a magnetic field up to 28 T, the Raman spectrum of GaAs exhibits three peaks: two correspond to coupled modes, and one to a resonance at twice the cyclotron frequency. The Raman spectra for different magnetic fields were calculated on the basis of a theory developed for this purpose. Fal'kovskii also explained how simultaneous observation of transverse and longitudinal modes can help in separating screening effects from electron–phonon coupling. This makes it possible to estimate through experiments the influence of electron–phonon interaction on phonon spectra.

While in ordinary 3D and even 2D systems the electron–electron interaction may not always manifest itself in full, in 1D and quasi-one-dimensional (q-1D) conductors this interaction may dramatically alter the properties of these conductors compared to those of ordinary metals. The report by S V Zaitsev-Zotov and V E Minakova (Institute of Radioengineering and Electronics, or IRE, RAS), named "Light-controlled collective phenomena in the Peierls TaS_3 conductor", was devoted to this interesting topic. Quasi-one-dimensional conductors with a charge density wave (CDW), such as TaS_3, belong to the class of physical systems with collective current transport. The interaction between electrons condensed in a CDW contributes the most to the elastic properties of the electronic crystal, the CDW, properties that determine such important characteristics of q-1D conductors as the value of the threshold field at which a CDW starts to slip (E_T), the phase correlation length, the dielectric constant, and so forth. The elastic properties of a CDW depend in turn on the current carrier (electrons and holes) concentration n, namely, carriers that are thermally excited across the Peierls gap in the energy spectrum and screen the electric fields generated in the process of deformation of the CDW. Thus, a change in n may serve as an instrument for controlling the properties of q-1D conductors with CDW. The researchers reported about the discovery of photoconductivity in TaS_3, and about the possibility of using light to control a number of effects caused by the presence of the electronic crystal, the CDW. They found that illumination of thin crystals of the q-1D TaS_3 conductor gives rise to substantial changes in the linear and nonlinear conductivities (photoconductivity). An increase in the linear conductivity G caused by illumination is accompanied by suppression of the nonlinear conductivity, an increase in the threshold field strength E_T, and the appearance of switching and hysteresis in the nonlinear conductivity. The effects exposed in the nonlinear conductivity may be explained by the decrease in the CDW elasticity modulus under illumination, which gives birth, among other things, to the dependence $E_T \sim G^{1/3}$, which is expected in the case of one-dimensional pinning. The researchers also discovered the prolonged relaxation of photoconductivity with a broad time spectrum up to 10^3 s, while the lifetime of the light-excited current carriers estimated by the value of the photoconductivity amounts only to $10^{-8}-10^{-10}$ s. Similar prolonged relaxation appears after an electric field whose strength exceeds the threshold value is applied to the sample. The researchers believe that this is proof of the existence of a CDW contribution to the photoconductivity, with the CDW being deformed when nonequilibrium current carriers are created by the light falling on the sample. Photoconductivity in q-1D conductors constitutes a much more complicated phenomenon than that in ordinary semiconductors because there is strong coupling between quasiparticles and CDWs. The origin of photoconductivity is still unclear — the possibility must not be ruled out that it is caused by collective excitations of CDWs (e.g., by solitons). Zaitsev-Zotov and Minakova believe that the possibility of controlling quasiparticle conductivity has great potential for studies of various static and dynamic properties of q-1D conductors with CDWs.

One of the most dramatic achievements of the last few years in the experimental physics of superconductivity was the discovery of superconductivity phenomenon in boron-doped diamond. The report by E A Ekimov (IHPP), named "The synthesis of metallic boron-doped diamonds with a record-high carrier concentration", along with the report by V A Sidorov, Ekimov, A V Rakhmanina, M V Kondrin, R A Sadykov (all from IHPP), and E D Bauer (Los Alamos National Laboratory, United States), named "New data on boron-containing diamond superconductivity" and presented in the poster section, were dedicated to this topic. In his report, Ekimov noted that boron (as well as phosphorus, nitrogen, and sulfur) is the main impurity element with which diamond is doped, but it is the only element that is capable of building itself into the diamond lattice in substantial concentrations. When boron concentration exceeds 0.1–0.3 at.%, a semiconductor–metal transition occurs. The

goal of the study reported was to produce metallic diamond with a record-high concentration of boron atoms and, correspondingly, a record-high concentration of carriers. Samples of metallic diamond were fabricated by synthesizing diamond from graphite in the presence of boron carbide (B_4C) subjected to a pressure of 8 GPa at temperatures higher than 2500 K. The level of boron solubility in diamond, achieved in this process, was more than 3%. Superconductivity with $T_c > 5$ K and a high value of the upper critical field (higher than 3.5 T) was discovered in diamond samples with a high boron concentration. The fabricated material was the first example of a superconductor with a diamond crystal lattice. In the second report devoted to this topic, the researchers presented new data on the superconductivity of boron-doped diamond. In particular, they discovered superconduction phenomenon in samples fabricated from a mixture of graphite and amorphous boron, and from a mixture of boron-containing hydrocarbons under high pressures. They also listed the results of examining the Hall effect, specific heat, and the lattice parameters of some samples. The anomaly detected in the specific heat suggests that the superconductivity of diamond bears evidence of its bulk nature, which is a discovery of great theoretical interest allows one to consider diamond as a promising material for the electronics of the future.

3. Quantum critical phenomena and magnetic properties

Eight reports were delivered in this section, and they were devoted to various aspects of the modern physics of magnetic phenomena, with the majority being reports of experimental work (six reports). The appearance of quantum criticality in low-dimensional magnetics was discussed in the report "Quantum criticality and EPR in low-dimensional magnetics" given by S V Demishev (GPI). Using 1% Fe-doped $CuGeO_3$ as an example, the researcher studied the quantum critical mode by a high-frequency (60 – 350 GHz) spectroscopy method in a record-broad temperature range 0.35 – 300 K. As is known, the magnetic Fe impurity completely suppresses the spin-Peierls and Néel transitions, at least down to 1.8 K, and stimulate quantum critical behavior. In the quantum critical mode, the Griffith phase proves to belong to the ground state, and for $T < T_G$, the magnetic susceptibility does not obey the Curie – Weiss law and becomes strongly divergent: $\chi(T) \sim 1/T^{\alpha}$, where $\alpha < 1$. Demishev presented the results of measuring the magnetic properties of the samples placed in the magnetic field oriented along the different crystallographic axes and those of a quantitative analysis of the shape of the electron paramagnetic resonance (EPR) lines. A SQUID magnetometer was used for absolute calibration of the integral intensity. The researcher found that the power divergence of $\chi(T)$ with $\alpha \approx 0.34$ is universal and can be followed down to 1 K, while the transition to the Griffith phase occurs at $T_G \approx 30$ K. At temperatures below 1 K, the χ vs. T plot exhibits a tendency toward saturation, but no long-range magnetic order was detected in this process. At the end of his talk, Demishev examined the applicability of the Oshikawa – Affleck theory, in which EPR in quantum spin chains is interpreted as an essentially collective effect. A detailed comparison of the theoretical and experimental results suggests that magnetic impurity doping stimulates the appearance of a field 'frozen' into $CuGeO_3$, and that this effect probably competes with antiferromagnetic correlations caused by the interaction between spin chains in the crystallographic *bc*-plane.

For magnetic systems with strong electron correlations there are theoretical predictions stating that pressure may induce an insulator – metal phase transition accompanied by a collapse of the localized magnetic moment and by a structural phase transition. In their report "Suppression of strong electron correlations in some oxides of 3D metals under high pressures", I S Lyubutin, A G Gavrilyuk, I A Troyan, and V A Sarkisyan (A V Shubnikov Institute of Crystallography, or IC, RAS and IHPP) summed up the latest results of experimental investigations on single crystals of yttrium garnet ferrite $Y_3Fe_5O_{12}$ and rare-earth orthoferrites $RFeO_3$, containing the Fe-57 isotope, and also on single crystals of iron borate $^{57}FeBO_3$. By using the methods of X-ray diffraction, Mössbauer absorption spectroscopy, nuclear resonance forward scattering, synchrotron radiation, optical absorption spectroscopy, and Raman scattering, as well as the results of direct measurements of electrical resistivity under pressures up to 140 GPa, it became possible to study in detail the magnetic and crystal structures, as well as the electron and transport properties of the above-mentioned materials.

The researchers found that, under pressures in the 38 – 50-GPa range, there appear abrupt transitions from the magnetic state to the nonmagnetic state in $FeBO_3$, $RFeO_3$, and $Y_3Fe_5O_{12}$, transitions caused by a structural phase transition accompanied by a jump in the unit cell volume and a transformation of the electronic structure of the iron ions. As a result of the Mott – Hubbard type transition with strong suppression of d – d electron correlations, the high-spin $3d^5$ states ($S = 5/2, {}^6A_{1g}$) of the Fe^{3+} ions transform into low-spin $S = 1/2, {}^2T_{2g}$ states. They also revealed that such spin crossover is accompanied by a sudden narrowing of the optical gap and a decrease in electron thermal activation energy, which suggests that an insulator – semiconductor transition occurs. However, complete metallization will, apparently, occur only under higher pressure, whose value is determined by the special features of the crystal structure. The researchers noted that $FeBO_3$ crystals exhibit magnetic correlations in the high-pressure phase, which are related to the magnetic ordering of Fe^{3+} ions in the low-spin state.

The report "Sm(Y)S: unstable valence and magnetism" presented by P A Alekseev, J-M Mignot, E V Nefedova, K S Nemkovskii, V N Lazukov, I P Sadikov, A V Golubkov, and A Ochiai (Russian Scientific Centre "Kurchatov Institute"; Laboratoire Leon Brillouin, or LLB, CEA-CNRS, France; A F Ioffe Physical-Technical Institute, or PTI, RAS, St.-Petersburg, and Tohoku University, Japan) covered various aspects of neutron studies of anomalous magnetism in strongly correlated electron systems. Samarium sulfide (SmS) is a well-known compound of the semiconductor type. Under external pressure ($\geqslant 0.6$ GPa) or because of substitution of yttrium for samarium (which is known as "chemical pressure"), partial delocalization of f-electrons takes place, with the result that the system transforms from the integer-valence (Sm^{2+}) state to the intermediate-valence state. Moreover, in SmS there is a strong exchange interaction of the magnetic moments of samarium ions through the unfilled d-band.

The goal of this work was to study the interrelation between the delocalization of f-electrons and the exchange interaction of samarium ions; with this object in view the researchers measured the neutron inelastic scattering spectra

for $Sm_{1-x}Y_xS$ ($x = 0$, 0.17, 0.25, and 0.33) single crystals at $P = 0$, and for stoichiometric SmS under a pressure of 0.4 GPa.

The magnetic excitation spectrum of a single-crystal SmS sample at normal pressure and low temperature contains a single dispersion magnetic mode which is related to the multiplet-to-multiplet spin–orbit transition $J = 0 \rightarrow J = 1$ for Sm^{2+}. They found that despite the spin and charge fluctuations accompanying the transition of samarium to the intermediate-valence state by virtue of the chemical pressure, exchange interaction between samarium ions is retained. Here, for the case where Sm resides in the intermediate-valence state, two excitations of a magnetic nature were detected in the $Sm_{1-x}Y_xS$ spectrum. The two excitations possess similar character of dispersion, which corresponds to the ferromagnetic type of correlations, and display strong intermode coupling. As the valence of the samarium ion increases (or the concentration of Y grows), the intensities of the magnetic modes become renormalized and their dispersions change significantly due, apparently, to the strengthening of the antiferromagnetic component of the exchange interaction. On the other hand, the application of an external pressure strengthens correlations of the ferromagnetic type. This effect may be caused by the significant difference between hydrostatic and chemical pressures, as well as the special features of the interaction between ions in the normal and intermediate-valence states.

Analysis of the spectra of $Sm_{1-x}Y_xS$ single crystals reveals that the appearance of an additional mode at a lower energy is caused by the transition of samarium into the mixed-valence state. This mode may be related to the magnetic excitation characteristic of a new exciton-like ground intermediate-valence state which retains the symmetry of the 'former' ground state of the $^7F_0$ type for Sm^{2+} in SmS. At the same time, it can be stated that the indirect exchange interaction between the samarium atoms through the d-band has a strong effect on the formation of the spectrum of f-electron excitations in SmS-based compounds, with the result that the new intermediate-valence state can be considered a collective excitonic mode.

Various instabilities determining the low-temperature properties of low-dimensional magnetics were discussed by A N Vasil'ev (Moscow State University, or MSU) in his talk "On some mechanisms of reaching the ground state in quasi-one-dimensional (q-1D) metal oxide $s = 1/2$-magnetics". He noted that the ground spin-singlet state in q-1D magnetics with half-integer spin may be reached via deformation of the crystal lattice. The alternative exchange interactions that emerge because of deformations in a spin chain lead to the formation of a spin gap separating the singlet state from the excited triplet states.

A classical example of the manifestation of magnetoelastic mechanisms, by which the ground state in q-1D metal-oxide $s = 1/2$-magnetics is reached, is provided by the spin-Peierls transition observed in $CuGeO_3$ at $T_c = 14$ K. The parameters of this transition in $CuGeO_3$, including the ratio of twice the width of the energy gap in the magnetic excitation spectrum, 2Δ, to the transition temperature T_c is close to 3.5, a value that follows from Bardeen–Cooper–Schrieffer (BCS) theory.

However, not only the magnetoelastic instability, which is the driving force of the phase transition in spin-Peierls magnetics, but also other physical processes may bring about elastic deformations and alternation of magnetic exchange in $s = 1/2$-chains. For instance, in a metal oxide NaV_2O_5 with a mixed valence of the magnetically active ions, the redistribution of charge between the positions $V^{4,5+} \leftrightarrow V^{4+}$, V^{5+} gives rise to a structural phase transition at $T_c = 34$ K; for this compound, the ratio $2\Delta/T_c \sim 6$.

In a metal oxide $NaTiSi_2O_6$ with the pyroxene structure, the TiO_6 octahedrons form distant helical chains. In view of the special features of the structure of this compound, the exchange between the magnetically active ions in the chains is done through the degenerate t_{2g}-orbitals of Ti^{3+} ions. The removing of this degeneracy via the Jahn–Teller instability at $T_c = 210$ K is accompanied by the formation of magnetic dimers with the ratio $2\Delta/T_c \sim 4.8$. Thus, the ratio $2\Delta/T_c$ can, probably, be used to estimate the various mechanisms by which the ground state is reached, namely, mechanisms conditioned by a variety of the crystal structures that allow for strong anisotropy of the exchange intra- and interchain interactions.

Of the reports that reflect the achievements in experimental research in this field, two were devoted to the synthesis and the study of physical properties of new promising materials serving as objects of inquiry for strongly correlated electron systems. G S Burkhanov (A A Baikov Institute of Metallurgy, or IMet, RAS) delivered the report "High-purity metallic substances for studies of strongly correlated electron systems".

High-purity metallic substances play an important role in investigating the strongly correlated electron systems. Trace impurities and defects in the crystal structure have a strong influence on the electrical and thermal conductivities, the specific heat, and the optical, magnetic, galvanomagnetic, superconducting, and other properties. The researcher analyzed the individual effects of impurities, dislocations, and vacancies on the thermal and electrophysical properties of pure metals, as well as intermetallic and metal-like compounds, involving borides and carbides of transition metals.

What is interesting here is that only high-purity TiB_2, ZrB_2, and NB_2 compounds are superconductors, while even commercially pure diborides do not exhibit superconducting properties. The study of the superconducting properties of high-purity borides made it possible to detect a number of new effects which were previously masked by impurities. In particular, anomalies in the temperature dependence of the upper critical field and in the field dependence of magnetization, as well as coexistence of superconductivity and ferromagnetism, were discovered in the YNi_2B compound. A sequence of paramagnetic–superconductor–ferromagnetic phase transitions caused by a drop in temperature was detected in another high-purity $Dy_{0.6}Y_{0.4}Rh_4B_4$ boride. It was found that gas-forming impurities largely determine the low-temperature specific heat of high-purity rare-earth metals and affect both its phonon component and the electron component. In the case of monoisotopic rare-earth metals, which possess an odd mass number and a large nuclear magnetic moment, it has been found that the nuclear component of the specific heat provides a significant contribution.

In their report "New magnetic semiconductors and semimetals—high-pressure Ga–Sb–Mn phases", V V Brazhkin, M V Kondrin, O A Sazanova, A G Lyapin, and S V Popova (all from IHPP) stated that they successfully synthesized under a pressure of 6 GPa in the 300–900-K temperature range new semiconducting and semimetal phases

in the Ga – Sb – Mn system, including supersaturated crystalline and amorphous solid GaSb:Mn solutions and new metastable Ga – Sb – Mn compounds with a structure of the $CuAl_2$ type and a simple cubic structure. Preliminary investigations showed that some of the new high-pressure phases in the Ga – Sb – Mn system are ferromagnetic with a Curie temperature higher than room temperature. It should be noted that although "diluted" tetrahedral semiconductors with an admixture of Mn, Co, Fe, or Cr are considered the most promising materials for spintronics, their potential use is limited to low (lower than 100 K) Curie temperatures. The new materials belonging to the Ge – Sb – Mn system are, apparently, free of these drawbacks.

The "theoretical segment" of the section consisted of reports covering the results of investigations of magnetics that are near the quantum critical transition and a new explanation of the genesis of the anomalous physical properties inherent in URu_2Si_2.

There are two reasons why cubic band magnetics with the Dzyaloshinsky – Moriya interaction (MnSi, FeGe, etc.) are interesting objects. First, they are in a state near the limit of the quantum transition to the nonmagnetic state, and this transition can be initiated by applying external pressure. Second, the Dzyaloshinsky – Moriya interaction destroys ferromagnetism and gives rise to a helical magnetic structure. Both phenomena are closely related; in particular, the critical magnetic fields in which the magnetic structure transforms are strongly dependent on pressure.

In his report "Cubic band magnetics with the Dzyaloshinsky – Moriya interaction", S V Maleev (B P Konstantinov Petersburg Nuclear Physics Institute, or PNPI) noted that the recent results of experiments in transforming the magnetic structure of MnSi and FeGe in a field and in critical neutron scattering cannot be fully explained by the well-known theoretical model that, in addition to ordinary exchange, includes the Dzyaloshinsky – Moriya interaction and anisotropic exchange, which determine the orientation of the helix in relation to the cubic axes of the crystal. It is this last interaction that is the weakest.

A more comprehensive theoretical investigation has shown that, in view of high cubic symmetry, the Dzyaloshinsky vector is directed along the critical fluctuation momentum. As a result, the area of small-angle scattering constitutes a circle circumscribing the direction (0, 0, 0), while the magnetic susceptibility tensor acquires a structure that differs dramatically from the standard Ornstein – Zernicke expression. As a consequence of the Dzyaloshinsky – Moriya interaction, the magnetic susceptibility tensor acquires an antisymmetric part which leads to a strong dependence of the scattering on the neutron polarization. As a result, only within a small neighborhood of the transition temperature is the anisotropic exchange "switched on", and there appear precursors of Bragg peaks and the neutron scattering becomes strongly dependent on direction. Such a theoretical picture agrees perfectly with the results of experiments.

Theoretical studies of the spin-wave spectrum at low temperatures have made it possible to clarify the nature of the two critical field strengths at which the magnetic structure transforms. The lower magnetic field, in which the axis of the helix rotates along the field, corresponds to the gap in the spectrum of spin waves that appears due to the interaction with electron – hole pairs. In the upper field, $g\mu H_c = Ak^2$, where A is the spin wave stiffness constant, and k is the magnitude of the wave vector of the helix, the system acquires ferromagnetic order. This result is in good agreement with the experimental data.

I A Fomin (P L Kapitza Institute for Physical Problems, or IPP, RAS) proposed in his talk " 'Hidden order' and a collective mode in the antiferromagnetic URu_2Si_2 phase" an explanation of the observed inconsistency between the normal magnitude of the specific heat discontinuity in the transition of URu_2Si_2 into the antiferromagnetic phase and the anomalously small magnetic moment of the sublattices. The theoretical model does not make the assumption that, in addition to antiferromagnetic order, this is another, 'hidden', order, which is often invoked to describe the above anomaly. Instead, the researcher suggested that the antiferromagnetic transition in the compound in question constitutes a Peierls transition with the doubling of the period and the opening of a gap in the conduction electron spectrum, the latter being responsible for the large discontinuity. The arguments in favor of such an explanation are the properties of the peak observed in the neutron inelastic scattering spectrum, which appears together with antiferromagnetic ordering. In the model proposed, the peak's intensity and the position of the peak as a function of the applied magnetic field are described well by the dependences expected for the collective mode that appears in the transition with period doubling.

4. Strongly correlated systems of a different nature

Six reports devoted to theoretical and experimental studies of various strongly correlated systems were presented in this thematic section.

It should be emphasized that recently there has been an upsurge of interest in the possibilities of Bose – Einstein condensation in various systems that differ from traditional helium-4. Yu E Lozovik (Institute of Spectroscopy, or IS, RAS) in his talk "The quantum phase transition and the coherent properties of a double-layer system of composite fermions" examined the electron properties of coupled quantum wells. The existence of superfluidity of interwell excitons in such a system was first predicted by Lozovik and V I Yudson in 1976. In the last decade, this system has been intensively studied by theoretical and experimental methods. Actually, a system of coupled quantum wells is a simple one: electrons and holes are contained in two parallel 2D planes implemented by semiconductor structures. Here, the interwell excitons are bound states of electrons from the conduction band of one plane and holes from the valence band of the neighboring plane. The wave functions of the electrons and holes overlap only slightly, thus significantly reducing exciton recombination. In this case, the exciton lifetime becomes so long that they can be thought of as metastable particles to which equilibrium statistical mechanics can be applied. In view of the fact that the electrons and holes are spatially separated, the excitons interact via a repulsive dipole – dipole potential, which prevents the system from collapsing. The report examined the problem of Bose condensation of excitons and strongly correlated states of an electron – hole system, and discussed the phases and coherent properties of the electron – hole system, in low-dimensional systems, such as quantum wells and coupled quantum wells. The researcher also analyzed the behavior of the system in strong magnetic fields, the representation of composite fermions, pairing in a two-component system of composite fermions, and, in particular, the special features of such a system related to

the deviation of the system's properties from those of an ordinary Fermi liquid.

Recently, the model of a Fermi – Bose mixture has become very popular. The model can be applied to various problems of the physics of the condensed media and, primarily, to the problem of high-T_c superconductivity, the problem of superfluidity in the ^{3}He – ^{4}He mixture, and the properties of systems of ultracold atoms in magnetic traps. Two following talks were devoted to investigations into the properties of Fermi – Bose mixtures. The report presented by M Yu Kagan, I V Brodskii, D V Efremov, and A V Klaptsov (IPP) and named "Composite fermions, triplets, and quadruples in a Fermi – Bose mixture with attraction" dealt with the two- and three-dimensional models of Fermi – Bose mixtures with strong short-range repulsion between particles of the same kind, and attraction between particles of different kinds. In this case, in addition to the standard anomalous averages of the type $\langle b \rangle$, $\langle bb \rangle$, and $\langle ff \rangle$, pairing of the type $\langle fb \rangle$ may appear in the system. Such pairing corresponds to the formation of composite fermions in the system. At low temperatures and equal fermion and boson number densities, composite fermions pair and form quadruples. At higher temperatures, the system also contains triplets, each consisting of a composite fermion and an elementary boson. The results obtained by these researchers are important for studies of high-T_c superconducting systems and in relation to the recent experimental discovery of resonant dimers in magnetic and optical traps at ultralow temperatures. They also play an important role in explaining the collapse of the Fermi gas in an attractive Fermi – Bose mixture of neutral particles in magnetic traps.

The stability of such a system was discussed by V N Ryzhov and E E Tareeva (both from IHPP) and S-T Chui (Bartol Research Institute, University of Delaware, United States) in their report "Collapse of the Bose component in a Fermi – Bose mixture with attraction between the components". Note that after Bose – Einstein condensation had been realized in the vapor of ultracold atoms of alkali metals in optomagnetic traps, the study of the behavior of mixtures of rarefied gases attracted a lot of attention. The reason for this was, primarily, the drive to find degenerate Fermi systems in order to discover superconductivity in them. However, theoretical investigations of the behavior of a mixture of bosons and fermions constitute a problem as itself. For instance, in view of Pauli's exclusion principle, in the s-wave approximation there can be no interaction of spin-polarized fermions, with the result that effective cooling of Fermi systems through evaporation is possible either via indirect interaction with the Fermi subsystem in another spin state or via the interaction with the boson subsystem in the Fermi – Bose mixture. In their report, the researchers present an effective Hamiltonian that describes the behavior of the Bose component in a mixture of fermions and bosons, and analyze the system's stability in the case of attraction between bosons and fermions. Due to the fact that the action is quadratic in the fermion operators because of the absence of interaction between fermions in the s-wave approximation, one can formally integrate over the Fermi fields and arrive at an expression for an effective action that depends on the number of fermions and temperature, and contains only bosonic fields. Using the semiclassical Thomas – Fermi approximation, the authors of the report obtained the explicit form of effective action, which can be expanded in a series in terms of the bosonic field. They also showed that the interaction with fermions weakens the effective interaction between bosons, corresponding to the fourth-order term in the expansion. In the case of attraction between bosons and fermions, the system's behavior is determined by the negative sixth-order term in the expansion over the bosonic field. In this case, by analogy with the system of bosons with attraction, one can use the variational principle with a Gaussian wave function of the bosons for evaluating the system's energy. The behavior of the system is determined by the competition between the positive kinetic energy of zero-point vibrations, caused by the presence of a trap, the positive energy of boson – boson repulsion, and the negative energy due to the sixth-order term in the expansion over the bosonic field. The last term grows in absolute value with increasing the number of fermions, which leads to an increase in the boson number density at the center of the trap. At a certain critical value of the number of bosons, the sum of the positive kinetic energy and the boson – boson repulsion energy is not large enough to stabilize the system, which finally leads to a collapse of the bosonic component. The critical number of bosons depends on the number of fermions and temperature. The results of calculations were applied to describing a system consisting of ^{40}K atoms (fermions) and ^{87}Rb atoms (bosons), with the theoretical prediction being in good agreement with the experimental data. From the qualitative viewpoint, the microscopic mechanism of the system's collapse can be understood, in particular, in light of the results of the previous report.

The diversity of the manifestations of strong correlation effects in physical systems and the complexity of the theoretical analysis of strongly interacting systems forces researchers to look for new theoretical methods that provide a meaningful description of such systems. One such method was applied in the report "The basics of the 'pseudoparticle' method of describing strongly correlated systems" by P I Arseev (FIAN) and N S Maslova (MSU). The first variant of this method was proposed in the mid-1960s by A A Abrikosov, but for a long time the "pseudoparticle" method remained undeveloped. The last decade has seen a revival of interest in this area of theoretical research, but no consistent construction of the diagrammatic technique within the pseudoparticle method has been developed so far. The method is based on taking into account from the very beginning the most significant part in the electron – electron interaction and then introducing operators corresponding to the exact state of the interacting system. The introduction of such pseudoparticle operators simplifies the Hamiltonian of the problem, but this requires introducing additional restrictions on the possible states and configurations of the pseudoparticles in such a way that states having no physical meaning do not appear. For instance, a description of paramagnetic impurities in the language of spins suggests that at an impurity site there can be only states with a single electron having one or another of the spin directions, while states with two electrons and states without electrons are forbidden. The research explains how to set up a diagrammatic technique for describing quantum systems that is based on such exclusion of a fraction of the possible states from consideration. It turns out that if we take into account exactly the limitation on the number of pseudoparticles, we arrive at a diagrammatic series of a very special kind, which does not resemble the ordinary series in the diagrammatic technique. In their report, the researchers also discuss the drawbacks of their method. For instance, what makes this theory so

complicated is that the disconnected parts of the diagrams do not cancel out and, generally speaking, the Dyson equation cannot be written in its standard form.

Two reports in the given section were devoted to the results of experimental research into compounds with strong electron correlations and semiconducting nanostructures.

In the last few decades, the nature of the ground state of the narrow-gap FeSi semiconductor ($E_g \approx 60$ meV) has been the subject of active discussions. The commonly accepted classification of iron monosilicide as a Kondo insulator contradicts the results of band calculations and is unable to explain a number of anomalies of physical properties observed in this compound having a simple cubic structure. An alternative approach to the description of the FeSi ground state within the Mott – Hubbard model shows that the low-temperature anomalies of the magnetic and transport properties can be related to a transition from the semiconducting state ($T > 100$ K), with spin excitations ($S = 1$) that have been thermally activated from the e_g-band to the t_{2g}-band, to a strongly correlated metal ($T < 100$ K) with band charge carriers. Here, the significant transformation of the band spectrum of FeSi in the strong-Hubbard-correlation mode is determined by the formation of a narrow multiparticle resonance ($E_r \approx 6$ meV) which corresponds to the production of spin polarons with a small radius (< 10 Å), a concentration on the order of 10^{17} cm^{-3}, and an effective mass $m^* \sim 100\, m_0$, where m_0 is the free electron mass. In their report "Charge transport in the FeSi compound with strong electron correlations", V V Glushkov, Demishev, I V Krivitskii, N A Samarin, N E Sluchanko (all from GPI), A Menowski (Van der Walls – Zeeman Laboratory, University of Amsterdam, The Netherlands), and V V Moshchalkov (Laboratorium voor Vaste-Stoffysica en Magnetisme, Leuven, Belgium) presented the results of investigating the peculiarities of charge transfer in the low-temperature strongly correlated state of FeSi. The researchers inquired into the galvanomagnetic properties of single-crystal samples on iron monosilicide within a broad range of temperatures (1.8 – 40 K) and magnetic field strengths (up to 70 kOe). By separating the normal (spin-polaron) and anomalous magnetic contributions to the Hall effect they found that the low-temperature inversion of the sign of the Hall coefficient is determined by the considerable change in the anomalous component of the Hall resistance, which increases by a factor larger than 10^5 as the temperature is lowered over the 1.8 – 20-K range. The appearance of an anomalous contribution to the Hall effect is related to the transition to the coherent regime of the electron density fluctuations in the vicinity of the Fe-centers, accompanied by the formation of ferromagnetic nanometer-sized (~ 10 Å) regions, or ferrons, in the FeSi matrix for $T < T_c = 15$ K. Near the temperature at which the sign of the Hall resistance is inverted, the researchers discovered an additional contribution to the Hall effect, a contribution that manifests itself in the form of a second harmonic in the angular dependences of the Hall resistance, whose presence cannot be explained within the commonly used phenomenological models. Research into the magnetoresistance of iron monosilicide in the temperature range corresponding to spin-polaron and coherent regimes of spin fluctuations has shown that $\Delta\rho(H)/\rho$ behaves complexly and nonmonotonically with sign inversion in the immediate vicinity of the mictomagnetic-phase boundary at $T_m = 7$ K. As a result of analyzing the experimental data, the researchers found that the linear asymptotic behavior of the negative magnetoresistance, $\Delta\rho/\rho \sim -H$, observed in weak magnetic fields ($\leqslant 10$ kOe) is the result of the formation of magnetic nanoclusters from interacting ferrons for $T < T_m$ in the mictomagnetic FeSi phase. Using these results, the authors of the report for the first time built the low-temperature magnetic phase diagram (H, T) of FeSi, made quantitative estimates of magnetic enhancement effects, and determined the effective parameters characterizing the electron subsystem in the paramagnetic ($T > T_c$), ferromagnetic ($T_m < T < T_c$), and mictomagnetic ($T < T_m$) phases of this compound with strong electron correlations. As a result of an analysis of the entire set of anomalies inherent in transport, magnetic, and magneto-optical characteristics observed in the vicinity of $H_m \sim 35$ kOe for $T < T_m$, they arrived at the conclusion that a new collinear magnetic phase with $\mathbf{M}\|\mathbf{H}$ exists in the low-temperature phase diagram of iron monosilicide.

The next report "The emission of semiconductor microcavities with quantum dots: the regime of strong interaction of an exciton at a single quantum dot with a photon mode", presented by V D Kulakovskii, M N Makhonin, D N Krizhanovskii (all from ISSP), G Sek, C Hofmann, R Krebs, A Loeffler, J P Reithmaier, A Forchel (all from the University of Würzburg, Germany), and L V Keldysh (FIAN), was devoted to one of the main areas of optical research into semiconductor nanostructures, namely, the problem of attaining strong coupling between quasi-zero-dimensional excitonic and photon modes. As is known, excitons are localized at quantum dots, while photons can be localized by modulating the refractive index in a semiconductor nanostructure, for instance, in a planar semiconductor microcavity with a limited lateral size (a tab microcavity). Such a system is bound to demonstrate the specific features inherent in a two-level atom interacting with the microcavity optical mode. Among these are the significant enhancement or suppression of the spontaneous emission rate in the weak-coupling regime (the Purcell effect), Rabi splitting in a vacuum electromagnetic field, the formation of mixed states in the strong-coupling regime, and so forth. In the first approximation, the energy of two interacting modes — the exciton at a quantum dot (X) and the microcavity (C) — can be written in the case of resonance ($E_X = E_C = E_0$) as follows:

$$E_{1,2} = E_0 - \frac{\mathrm{i}(\gamma_C + \gamma_X)}{2} \mp \left[g^2 - \frac{(\gamma_C - \gamma_X)^2}{4} \right]^{1/2},$$

where $\gamma_{C(X)}$ is the half-width of the microcavity (excitonic) mode at half-height (for real microcavities, $\gamma_C \gg \gamma_X$), $2\gamma_C = E_C/Q \gg \gamma_X$, $g \sim (f/V_m)^{1/2}$ is the excitonic – microcavity-mode coupling constant, f is the oscillator strength of the exciton at the quantum dot, and V_m is the effective mode volume. According to this formula, the strong-coupling regime is realized in a microcavity only for $g > (\gamma_C - \gamma_X)/2 \sim \gamma_C/2$. When $g < \gamma_C/2$, the weak-coupling regime is realized, and the exciton – photon coupling enhances the radiative damping of the excitons. This regime has been achieved in a microcavity with self-organizing quantum dots. To implement the strong-coupling regime, one must increase the Q-factor of the microcavity and/or the oscillator strength of the exciton at the quantum dot (by increasing the lateral size of the quantum dot). In their report, the researchers gave the results of studies of high-Q tab microcavities with quantum dots of various sizes in the 10 – 45-K temperature range. The weak-coupling regime was realized in structures with small-sized quantum dots, while

the strong-coupling regime was realized in structures with larger-sized quantum dots. It was found that in both regimes the microcavity emission spectrum is determined by the mechanism of primary excitation, namely, depends on whether excitation is realized via an excitonic mode or via a cavity mode. In particular, calculations show that in the latter case the dip in the emission line manifests itself already in the weak-coupling regime. Despite the fact that in the interband excitation of microcavity structures the excitation occurs mainly via an excitonic mode, even partial excitation of a microcavity mode gives rise to a significant change in the relative intensity of microcavity and quantum-dot lines far from the resonance and to a splitting of the emission line at resonance near the threshold of the strong-coupling regime. The strong-coupling regime was achieved for a microcavity 1.5 μm in diameter and with a Q-factor of 7500. The maximum splitting of the emission line at the resonance of microcavity and quantum-dot modes proved to be equal to 0.14 meV.

5. Poster section

A number of reports presented in the poster section were devoted to the experimental study of the transport and magnetic properties of strongly correlated electron systems and systems with heavy fermions. In their report "Low-temperature transport regimes in CeM_2 compounds with heavy fermions", M I Ignatov, A V Bogach, G S Barkhanov, V V Glushkov, S V Demishev, N E Sluchanko, and O D Chistyakov (GPI, Moscow Institute of Physics and Technology, or MIPT, and IMet) noted that the complexity of interpreting the transport properties of compounds with heavy fermions, the concentrated Ce-, Sm-, and Yb-based Kondo systems, and other compounds with strong electron correlations proves to be directly related to the problem of meaningful accounting for the rapid spin and charge fluctuations which initiate a substantial renormalization of the spectrum of quasiparticle excitations in the systems indicated. To ascertain the nature of the anomalies in the transport properties, caused by local fluctuations in the electron density, the researchers studied the conductivity σ, the thermoelectric coefficient (S), and the Hall coefficient (R_H) of intermetallic compounds possessing a Laves phase structure, CeM_2 (M = Al, Ni, Co, Ru, Rh, and Ir), within a broad temperature range 10–300 K. By changing the structure-forming element in the CeM_2 series it is possible to vary the Ce valence within broad limits: from almost integer values $v \approx 3.04$ ($CeAl_2$) to intermediate values $v = 3.35-3.36$ ($CeCo_2$ and $CeRu_2$). Analysis of the experimental data has shown that a consistent description of the transport characteristics of CeM_2 compounds may be obtained through a phenomenological approach that allows for the qualitative transformation of the electronic structure and is based on an analysis of several additive contributions to the parameters σ, $S\sigma$, and $R_H\sigma^2$. In the case of $CeAl_2$, it was shown that high-temperature ($T > 50$ K) transport is determined by the inelastic scattering of charge carriers, accompanied by transitions between the doublets of the cerium $^3F_{5/2}$ state split in the crystal field. A drop in temperature leads to a substantial alteration of the behavior of the $CeAl_2$ transport coefficients which exhibit activation-type asymptotics $S \sim \exp(E_a^S/k_BT)$ and $R_H \sim \exp(E_a^H/k_BT)$ with the parameters $E_a^S \approx 3.6$ K and $E_a^H \approx 7$ K. The anomalous behavior of S and R_H in a heavy-fermion system can be related to the formation of a narrow band of multiparticle states in the vicinity of ε_F and, subsequently, with the formation of ferromagnetic nanoclusters of spin-polaron states for $T < 20$ K.

In CeM_2 compounds based on transition metal elements (M = Ni, Co, Ru, Rh, and Ir), the low-temperature contribution to conductivity is determined by a dependence conforming to a Fermi-liquid behavior: $\sigma^{-1} \sim T^2$, and makes it possible to meaningfully describe the anomalies in the temperature dependences of the parameters $S\sigma$ and $R_H\sigma^2$. A rise in temperature changes the nature of charge carrier scattering, with estimates of the microscopic parameters of the charge carriers indicating the presence of a crossover of the different transport regimes in the temperature interval $T \sim 50-199$ K. The authors explain the anomalous behavior of transport characteristics in the CeM_2 compounds by anisotropic f–d hybridization and the formation of multiparticle states in the neighborhood of Ce-centers.

Bogach, Burkhanov, Glushkov, Demishev, Sluchanko, and Chistyakov (GPI, MIPT, and IMet) presented the report "Multiparticle states in $Ce(Al_{1-x}Ni_x)_2$ and $Ce(Al_{1-x}Co_x)_2$ systems with heavy fermions" on their detailed study of collective effects in some substitutional solid solutions based on $CeAl_2$. The results of recent experiments involving the transport properties of what is known as the magnetic $CeAl_2$ Kondo lattice have made it possible to establish the activation nature of the behavior of the Hall coefficient for this intermetallic compound with heavy fermions. To ascertain the extent to which substitutional disorder affects the formation of anomalies in the Hall coefficient in cerium systems with heavy fermions and metallic conductivity, the researchers studied the transport characteristics of substitutional solid solutions $Ce(Al_{1-x}Ni_x)_2$ and $Ce(Al_{1-x}Co_x)_2$ with $x = 0.05$. Their results led to the following conclusions.

First, the binding energy of multiparticle states being formed as $T \geqslant 70$ K varies substantially (from $E_{a1}(CeAl_2) \approx 12$ K to $E_{a1}(Ce(Al_{0.95}Co_{0.05})_2) \approx 42$ K) as cobalt is substituted for aluminium. Here, the binding energy of heavy-fermion states which determine the characteristics of low-temperature ($T < 70$ K) transport remains practically unchanged, to within $E_{a2} \approx 6-8$ K. Second, substitutional disorder leads to suppression of the coherent regime observed in $CeAl_2$ at liquid-helium temperatures. As a result, the temperature dependence of the Hall coefficient with a peak is replaced by a dependence with a tendency toward saturation. The experimental results obtained can be consistently interpreted within the models of spin-polaron transport of charge carriers in strongly correlated electron systems.

As follows from the report "Magnetoresistance in $CeCu_{6-x}Au_x$ and $CeAl_2$ compounds with heavy fermions" presented by Bogach, Burkhanov, Glushkov, Demishev, D N Sluchanko, N E Sluchanko, and Chistyakov (GPI, MIPT, IMet, and MSU), the given transport characteristic may prove to be highly informative in investigating the heavy-fermion systems and systems resided in the vicinity of the quantum critical point. In particular, among the Ce-based intermetallic compounds there has been lately an upsurge of interest in $CeCu_{6-x}Au_x$ compounds, whose physical parameters exhibit at $x \approx 0.1$ quantum critical (non-Fermi-liquid) behavior. Incidentally, in the immediate vicinity of the quantum critical point there exists a $CeCu_6$ compound with heavy fermions, characterized by a record-high effective mass of charge carriers, and a magnetic $CeCu_{5.8}Au_{0.2}$ Kondo

lattice for which the ground magnetically ordered state is formed in conditions where multiparticle effects have considerable magnitude.

The study of the magnetoresistance in the Ce-based intermetallic $CeCu_{6-x}Au_x$ compounds and solid solutions $Ce(Al_{1-x}Ni_x)_2$ and $Ce(Al_{1-x}Co_x)_2$ with $x = 0$ and 0.05, located within a broad area around the quantum critical point, has shown that the data on the temperature and field dependences of the magnetoresistance, $\Delta\rho(T, H)$, of these compounds with heavy fermions and a quantum critical behavior may be consistently interpreted with the Yoshida model for the scattering of charge carriers by the localized magnetic moments of rare-earth centers. Here, the effective local susceptibility of heavy charge carriers, $\chi_{loc}(H, T) \sim (1/H\,d\rho/dH)^{-1/2}$, found from magnetoresistance measurements, can be applied to estimating the renormalization of the electron density of states near the Fermi energy.

The results of investigations of the magnetic susceptibility of a single crystal of the heavy-fermion $CePd_2Si_2$ compound in strong pulsed magnetic fields (up to 50 T) for two directions of the magnetic field in the 4.2 – 15-K temperature range were presented by A V Semeno (GPI) in the report "Localized magnetic moments in $CePd_2Si_2$: a study in pulsed magnetic fields up to 50 T". The researcher was able to show that when the magnetic field is directed along the (100) axis, the field dependence of magnetization is defined by a sum of two contributions: the magnetization of the localized magnetic moments, which tends to become saturated in strong fields, and the contribution from band electrons, which is linear in field strength. Below the Néel point ($T_N \sim 8.5$ K), the field dependence of the magnetization of localized moments is well described by the model of antiferromagnetism with an easy anisotropy axis; here, magnetic transitions caused by the flip and collapse of magnetic moments may be observed. Saturation of the magnetization of localized electrons was used to determine the average magnetic moment per cerium atom, which was found to be equal to $0.35\mu_B$ at $T \sim 5$ K. As the temperature grows, the magnitude of the magnetic moment M decreases, with the extrapolation of the experimental dependence $M(T)$ to the high-temperature region predicting the disappearance of localized moments at $T \sim 30$ K. When a magnetic field is applied along the (001) axis, the field dependence of magnetization diverges only slightly from a linear one for field strengths up to the maximum one within the entire temperature range, and does not undergo a dramatic change in the vicinity of T_N. Such behavior can be explained by the delocalization of 4f-electrons with the magnetic moment directed along the (001) axis and, as a consequence, by the band nature of the magnetism.

The report "Dynamic magnetic correlation effects in the inelastic neutron scattering spectra of $CeAl_3$" by N N Tiden, Alekseev, Lazukov, Sadikov (all from the Russian Research Centre 'Kurchatov Institute') and R Kahn and J-M Mignot (LLB) described the results of studies of the ground state of the heavy-fermion $CeAl_3$ system at low temperatures by the method of neutron magnetic scattering. Recent investigations have shown that in the crystal electric field (CEF) for $T < E_{CEF}$ there is a rapid increase in energy and a decrease in intensity of the transition between the f-electron ground and first excited states. At $T \sim T_K$ (here, T_K is the Kondo temperature), all observed effects become more pronounced. Apparently, when $T < E_{CEF}$, such a behavior can be explained by the presence of a strong exchange interaction and magnetoelastic effects, while at $T \sim T_{CEF}$ the peculiarities observed can be explained by the production of a strongly correlated state of spins of the fundamental doublet — the spin liquid. The formation of the spin-liquid state must lead to an oscillatory dependence of the intensity of quasielastic magnetic scattering on the transferred momentum in the inelastic neutron magnetic scattering spectra. The researchers attempted to verify through experiments the above behavior patterns. To this end, they measured the spectra of inelastic neutron scattering by a polycrystalline $CeAl_3$ sample at 2, 7, 40, and 80 K with the transferred momentum Q varying from 0.5 $Å^{-1}$ to 2.5 $Å^{-1}$. In these experiments, the initial neutron energy was 3.27 meV, which guaranteed the necessary energy and momentum resolutions. The measurements were taken on the time-of-flight spectrometer MIBEMOL (LLB). To estimate the background and phonon components, measurements were done with an empty container at 2 and 80 K, and with an $LaAl_3$ sample at $T = 80$ K. The obtained width of the quasielastic component of magnetic neutron scattering agrees fairly well with the already known results. At $T = 2$ and 7 K, the researchers discovered an oscillatory dependence of the quasielastic scattering intensity, while at $T = 40$ and 80 K there were no oscillations. They believe that on the whole their results support the assumption that it is possible to describe the states with heavy fermions at $T \sim T_K$ as spin-liquid states with resonating valence bonds.

The report "A Kondo type effect in a double 2D electron tunnel system" by V A Volkov (IRE) and Yu V Dubrovskii and E E Vdovin (Institute for Microelectronics Technology and High-Purity Materials, or IMT, RAS) examined the behavior of the tunneling conductivity in coupled quantum wells. Studies of tunneling between disordered 2D electron systems, where the interlayer Coulomb interaction exceeds the intralayer one, showed that systems exhibit an anomalously high equilibrium tunneling conductivity. The 2D electron systems were formed by δ-doping of quantum wells separated by a 5-nm thick tunnel barrier. The electron concentration in the layers was the same, $N_e = 2.6 \times 10^{11}$ cm^{-2}, with a 5% accuracy. Anomalous conductivity manifested itself at $T = 0.3$ K in the form of a narrow peak in the dependence of the incremental tunneling conductivity on external bias over the tunnel structure. The peak's maximum was found at exactly zero external voltage; the peak's half-width amounts to 0.5 meV, and its amplitude is 50% of the background conductivity. Control samples with a 15-nm barrier and thicker ones showed no picks of anomalous conductivity. The researchers carried out thorough measurements of the magnetic-field and temperature dependences of the anomalous conductivity. It was found that in a magnetic field, either parallel or perpendicular to the tunnel current, the anomalous peak is suppressed. It also disappears if the temperature is raised to 3 K. Of greatest interest are the temperature characteristics measured in a magnetic field. It turns out that within certain temperature and field-strength ranges the magnetic-field-suppressed anomalous peak is restored as the temperature raises. The researchers assume that the observed anomaly can be explained within the realm of the physics of Kondo systems.

The properties of Kondo systems were also discussed in the report "Spin gap and dispersion of magnetic excitations in the YbB_{12} Kondo insulator" by Nemkovskii, Alekseev, Lazukov, Nefedova, Sadikov, Tiden (all from the Institute of Superconductivity and Solid State Physics, or ISSSP, of

the Russian Research Centre 'Kurchatov Institute'), Mignot (LLB), F Iga (ADSM, Hiroshima University, Japan), and L-P Renault (DRFMC/SPSMS, CEA, Grenoble, France). The YbB_{12} compound is a typical representative of a special class of rare-earth compounds known as Kondo insulators. Earlier experiments in inelastic neutron scattering by a polycrystalline Yb(Lu)B_{12} sample revealed an unusual spectrum of magnetic excitations, which at $T \sim 10$ K exhibited a spin gap of roughly 10 meV and a fine structure formed by three peaks with energies $E_1 \approx 15$ meV, $E_2 \approx 2$ meV, and $E_3 \approx 40$ meV. Upon embedding nonmagnetic impurities (Lu ions) into YbB_{12}, the spin gap is retained but the low-energy E_1 and E_2 peaks in the YbB_{12} spectrum become strongly smeared, which suggests that coherent effects play an important role in the rare-earth sublattice, when this part of the excitation spectrum is formed. To study the collective magnetic excitations in YbB_{12} in greater detail, the authors of the report measured the inelastic neutron scattering spectra for a single-crystal YbB_{12} sample, and found that the two 'coherent' peaks in the YbB_{12} spectrum at low temperatures correspond to two dispersion modes, M_1 and M_2, with a nontrivial dependence of the intensity on the reduced wave vector $\mathbf{q}$ and temperature. As we move closer to the center of the Brillouin zone, the intensity of both modes decreases substantially and, apparently, finally vanishes. Here, the mode M_1, which is the lowest in energy, is localized to the greatest extent in momentum space and possesses maximum intensity in the ($\xi\xi\xi$) direction near the Brillouin zone edge, which may be related to the presence of antiferromagnetic correlations with a wave vector $\mathbf{k} = (1/2, 1/2, 1/2)$. An insignificant (compared to the energy of these two modes) rise in temperature suppresses the M_1 mode and results in the appearance of a wide quasielastic signal (with a half-width $\Gamma/2 \sim 15$ meV).

Several reports were devoted to studies of the properties of low-dimensional systems. A V Syromyatnikov and S V Maleev (both from PNPI) examined the behavior of frustrated magnetic systems in their report "Chiral fluctuations in a quantum $CsCuCl_3$ antiferromagnetic with a triangular lattice at $T = 0$". Among such systems, antiferromagnetics with a triangular lattice occupy a special place. For instance, H Kawamura proposed a new universality class for such systems, and recently Maleev indicated a way of verifying this theory on the basis on experiments in chiral scattering of polarized neutrons. The results of the first experiments of this kind, which involved a $CsMnBr_3$ sample, are in satisfactory agreement with the theoretical results. The $CsCuCl_3$ compound is one more object that is of interest in this connection. A characteristic feature of this compound is that it contains chains of ferromagnetically interacting copper atoms along the *c*-axis. In the *ab* plane, these atoms form a triangular lattice, with the exchange in this plane being antiferromagnetic and six times as strong as the exchange interaction along the chains. The Dzyaloshinsky–Moriya interaction also plays an important role in $CsCuCl_3$, and this results in magnetic helixes formed along the *c*-axis. Here, the angle of deflection of neighboring spins along the helix is approximately 5.1°. At $T_c \approx 10.7$ K, the substance undergoes a transition to an ordered phase, in which the ground state of $CsCuCl_3$ is a 120-deg. ordering of spins in the *ab* plane. The researchers examined the chiral fluctuations in $CsCuCl_3$ at $T = 0$. Using linear spin-wave theory, they arrived at expressions for the off-diagonal component of the spin magnetic susceptibility tensor, which describes chiral fluctuations. They found that in this case, because of frustration, there can exist two nonequivalent ground states with a 120-deg. structure. In these states, spin configurations with different values of the chirality of triples of neighboring spins are realized. The authors also found that in a single-domain sample this component is nonzero even when there is no Dzyaloshinsky–Moriya interaction or magnetic field. The first corrections in $1/S$ to this quantity were also determined. It turned out that these corrections are large in the case of equal domain concentrations in the sample, and an analysis of the entire $1/S$-series is needed. Since the chiral contribution to the polarized neutron scattering cross section is related to the chiral component of the magnetic susceptibility tensor, the authors of the report discussed the possibility of studying the discovered peculiarities through experiments.

In the report "Stabilization of the Luttinger liquid by impurities in quasi-one-dimensional conductors", S N Artemenko (IRE) considered the electron properties of 1D metals, interest in which is caused to a great extent by the rapid development of the physics of carbon nanotubes and low-dimensional semiconductor structures. As is known, the electron properties of 1D metals differ dramatically from the properties of ordinary 3D metals, which are well described by Landau's theory of a Fermi liquid. The elementary excitations in a 3D metal are the slowly decaying one-electron excitations which behave like noninteracting particles. In contrast to the 3D case, the Fermi-liquid theory does not work in a purely 1D electron system for an arbitrarily weak electron–electron interaction — there are no quasiparticles in a 1D metal, and the only elementary excitations are collective charge and spin modes with an acoustic spectrum. The generic name for electron liquids with such properties is 'Luttinger liquid'. At the same time, the use of the Luttinger-liquid concept in describing q-1D conductors, i.e., highly anisotropic conductors with a chain structure, is confronted with difficulties, the reason being that the Luttinger liquid is unstable for an arbitrarily low probability of electron transitions between the conducting chains. The report discussed a possible mechanism of stabilizing the Luttinger liquid by introducing impurities, which makes it possible, at least in principle, to employ this approach in interpreting experiments involving q-1D conductors. As is known, an impurity in the Luttinger liquid is, for all practical purposes, an infinitely high barrier for low-energy excitations, so that the Luttinger liquid must effectively 'split' into separate finite segments. This gives rise to size quantization of the collective modes and, consequently, to the appearance of a minimum excitation energy $E_{\min}$. As a result, transitions between chains will lead to small perturbations which do not destroy the Luttinger liquid at temperatures $T < E_{\min}$. To corroborate this qualitative picture, the author of the report first studied the gapless 1D Tomonaga–Luttinger model to which an impurity potential was added. The researcher showed that impurities do indeed split the system into a set of practically independent Luttinger-liquid segments with a discrete energy spectrum. Next, the corrections to the thermodynamic potential and to the one-particle Green's function were calculated (these corrections emerge because of weak interchain transitions), and it was shown that they are indeed small at low temperatures. The report also discussed the possibility of generalizing the Tomonaga–Luttinger model in order to incorporate the more realistic case of the Coulomb interaction, and the possibility of implementing the Luttinger-liquid

concept through experiments involving q-1D materials, and compared the results with the experimental data.

It is common knowledge that the key to understanding the unusual kinetic properties of the normal state of high-T_c superconductors lies in the properties of the carriers in the CuO_2 plane, properties that almost ideally coincide with those of a doped 2D antiferromagnetic. Most theoretical papers that set out to give a microscopic description of kinetic coefficients usually use the phenomenological spin susceptibility which corresponds to rapidly decaying paramagnons, and the carrier spectrum is chosen on the basis of parametrization of the Fermi surface observed by angle-resolved photoemission spectroscopy (ARPES). In their report "On the question of the temperature dependence of the kinetic coefficients in high-T_c superconductors. The dependence on spin susceptibility", A M Belemuk, A F Barabanov (both from IHPP), and L A Maksimov (Russian Research Centre 'Kurchatov Institute') studied the temperature dependences of the electrical resistivity $\rho(T)$ and the Hall coefficient $R_H(T)$ for a doped 2D antiferromagnetic within the Kondo-lattice model with allowance for the real spectrum of the carrier band, which corresponds to ARPES data and was obtained in the spin-polaron approximation for the lower quasiparticle band of the current carriers. It is assumed that the carriers are scattered by antiferromagnetic fluctuations of the system of localized spins, which in the absence of long-range order is considered in the spherically symmetric approximation with allowance for spin frustration. To find the kinetic coefficients, the authors of the report used a multiple moment method of solving the kinetic equation, which makes it possible to simultaneously analyze the temperature dependence of nonequilibrium distribution functions in electrical-resistivity and Hall-effect problems. It was revealed that carrier scattering is caused mainly by the low-lying spin excitations (with energies in the 100–500-K range) with momenta close to the antiferromagnetic vector $\mathbf{Q} = (\pi, \pi)$, at which there is a gap in the spin excitation spectrum, whose size is determined by the temperature and the spin frustration parameter. This results in a strong scattering anisotropy which rapidly varies with temperature and is also determined by the nature of the magnons whose momenta is close to the antiferromagnetic vector $\mathbf{Q}$. The researchers studied the dependence of this anisotropy on spin susceptibility and found that for the spin susceptibility within the framework of antiferromagnetic liquid that corresponds to rapidly decaying paramagnons the scattering anisotropy is heavily suppressed by the rapid decay of the magnons. They also found that for different degrees of doping this scattering mechanism explains both the linear temperature dependence $\rho(T)$ (down to very low temperatures) and the nontrivial rapid increase in the Hall constant $R_H(T)$ with decreasing temperature; both peculiarities have been examined in experiments with high-T_c superconductors in the normal state. The researchers also studied the dependence of the additional nonequilibrium term in the distribution function on the number of moments and revealed that several moments are needed if a meaningful description of the low-temperature behavior of the Hall coefficient is to be obtained. On the whole, a well-developed multiple moment approach to solving the kinetic equation makes possible a proper description of the scattering anisotropy and the temperature transformation of the nonequilibrium distribution function of the carriers.

The methods described in the previous report in connection with 2D magnetics were applied in a nontrivial manner to developing a model for the liquid state. Lately, the researchers exploring the behavior of liquids took an active interest in the problem of the occurrence in liquids of phase transitions between phases with the same symmetry, similar to the liquid–gas transition. Such phase transitions have been emerged from the observations of a number of dense liquids. It is assumed that the unusual properties of water (e.g., the negative thermal expansion coefficient) can be explained by the existence of a transition between denser and less dense modifications in the supercooled region. However, the theory of such transitions is far from completion. The existence of liquid–liquid transitions is determined by the shape of the intermolecular potential. At present there can be no doubt that such transitions occur in systems with a negative curvature of the potential, for instance, the hard-sphere potential to which a repulsive step is added.

In their report "The spin-liquid approach to the classical theory of liquids", A V Mikheenkov, Barabanov (both from IHPP), and Maksimov (Russian Research Centre 'Kurchatov Institute') proposed the simplest possible lattice model of a 2D liquid based on a 2D-frustrated Heisenberg model, which makes possible a qualitative description of the behavior of the pair correlation function in the case of two-step potentials. The authors of the report examined a 2D liquid with an average density ρ_0. To allow for fluctuations in the simplest possible way, the local density operator was represented in the form $\rho = \rho_0 + \alpha S^z$, where S^z is the spin-1/2 projection operator. Of primary interest here is the density–density correlation function $c_{ij} = \langle S_i^z S_j^z \rangle$. The lattice model amounts to dividing the plane into square meshes with an appropriately chosen constant a; inside each mesh all the parameters are assumed constant, and only the interaction between the first and second neighboring meshes is taken into account (i.e., the potential is two-step). If we now allow for the movement of density fluctuations over the system, the system's behavior is described by a frustrated Heisenberg Hamiltonian (only the particular case where the coefficients of the longitudinal and transverse terms are the same is considered below): $H = J_1 \sum_{ig} S_i S_{i+g} + J_2 \sum_{id} S_i S_{i+d}$, where J_1 and J_2 are the heights (depths) of the first and second steps in the potential, while g and d are the first and second nearest neighbors, respectively. In the model formulated in terms of spin operators, intrasite repulsion of fluctuations automatically becomes infinite. It is essential that for describing the liquid we must assume that within the spin problem for the 2D-frustrated Heisenberg antiferromagnetic the average values of the longitudinal and transverse components of the spin at each site are zero, i.e., we must apply the spin-liquid approach. The problem is solved by uncoupling the equations of motion for two-time temperature Green's functions in the second step, which enables one to get the complete picture of correlators. The authors of the report believe that their approach makes it possible to establish the qualitative behavior of pair correlators as the parameters of the potential vary. In particular, they found that the emergence of a local minimum in the repulsive part of the potential may lead to formation of a molecule. Furthermore, they discovered the nonmonotonic temperature behavior of the correlators in the case of a two-step potential, or to put it differently, the possibility of a liquid–liquid transition.

Lately, the study of spin-polarized current states has attracted the attention of both theoreticians and experimen-

ters. The results of a theoretical study of the properties of 'quantum wires' were presented by V A Sablikov and S V Polyakov (both from IRE) in their report "The charge and spin structure of a quantum wire with spontaneously broken spin symmetry". As is known, spin symmetry may be spontaneously broken in quantum wires of finite length, which is due to the redistribution of the electron density between the wire and the reservoirs that this wire connects. The report analyzes the possible spin states of quantum wires in relation to the shape of the contact. The researchers showed that in a wire with abrupt contacts at the reservoirs, the electronic state is characterized by the presence of antiferromagnetic ordering in spin and by the presence of charge ordering close to the Wigner type. The spin density distribution exhibits oscillations with a wave vector close in absolute value to $2k_F$ (k_F is the value of the Fermi wave vector), while the charge density has an oscillating component with a wave vector whose length is close to $4k_F$. It turned out that, depending on the level of the chemical potential, there can be two types of states, which differ in total spin and in the symmetry of the spin density distribution. In the state with zero total spin, the spin density distribution is an odd function of the coordinate. In this case there can be spontaneous spin polarization at the contacts, with the directions of this polarization being opposite at the wire ends. In the polarized state with nonzero total spin, the spin density distribution is an even function of the coordinate, with one spin component spontaneously exceeding the other component, i.e., a state of the ferrimagnetic type comes about. Polarized and unpolarized states emerge when the level of the chemical potential of the system lies within certain energy bands in respect to the bottom of the conduction band in the wire. The presence of such bands is related to resonances of charge and spin waves over a length of the wire. The authors of the report also examined a mechanism of formation of quasibound states in quantum wires with adiabatic transitions to the reservoirs in the quantum contacts. They found that this mechanism originates in the Friedel oscillations of the electron density, which emerge because of reflections at these oscillations of electrons that belong to high-dimensional subbands and are unable to travel along the wire. The interaction with these oscillations of electrons belonging to open subbands gives rise to backscattering and the formation of resonances in the wire. The results were obtained in the Hartree–Fock approximation without restrictions on the dependence of the wave functions on the spin variable. The computing method employed makes it possible to determine the amplitude of charge oscillations whose existence also follows from the Luttinger-liquid theory where, however, their amplitude remains undefined. The researchers found that the amplitude of $2k_F$-oscillations of the spin density is much larger than the amplitude of $4k_F$-oscillations of the charge even in the case of Coulomb interaction.

Controlling individual spins and spin fluxes (spin currents) in nanostructures constitutes the main problem of the new, rapidly developing area of science known as spintronics. In his report "Spin transport in superconducting hybrid junctions", N M Shchelkachev (ITP) discussed the possibility of using Andreev quantum dots (AQDs) as a controlling element for spin currents. The researcher established that AQDs can serve as a spin filter, i.e., they can spatially separate the spin and charge currents; on the other hand, AQDs can help localize spin and control it, and lastly AQD arrays could be used for quantum computing. In the first case, AQDs act as hybrid junctions of the normal metal (ferromagnetic)–superconductor–normal metal type; here it is assumed that the transparency of the interface between the layers is much smaller than unity, for instance, due to the presence of thin insulator layers, and the thickness of the superconductor does not exceed the coherence length. If we assume that the superconductor and one conductor are grounded, while the current of spin-polarized electrons flows from the second conductor to the superconductor's boundary (the potential of the second conductor is smaller than the superconducting gap), then almost the entire charge current goes into the superconductor, while the respective spin current will attend to the first conductor. This effect occurs because the superconductor acts as a Fabry–Perot cavity for the Bogolyubov quasiparticles, with a 1/2 probability tunneling from the respective quasistationary state in the superconductor to the (first) normal metal — into an electron or hole state. The above effects play an important role in describing how the domain structure of a ferromagnetic affects the electron transport in a superconductor–ferromagnetic system. When the ferromagnetic is almost completely polarized, the domain walls provide the main contribution to the conductance of the junction. It is a well-known fact that Josephson junctions may contain bound states of Bogolyubov quasiparticles, which are known as Andreev states, with the conclusion that such a system may also be called an AQD. Spin can be shown to be a good quantum number for such states (say, in superconductor–normal metal–superconductor junctions). The ground state of such a junction has zero spin. In this case, the excited state with spin-1/2 has a long lifetime, which makes it possible to manipulate this state. The value of the Josephson current can be used to foresee the spin state in AQDs, while such an excited state can be obtained, say, by irradiating the junction with microwave radiation. The author also discusses how we are able to manipulate the quantum states of AQD arrays and carry out computations.

In their report "The phase diagram of the band $ZrZn_2$ ferromagnetic", Stishov, Sidorov, A V Tsvyashchenko, L N Fomicheva, A E Petrova (all from IHPP) and E D Bauer and J Thompson (both from the Los Alamos National Laboratory, United States) presented the results of measurements of the electrical resistance and magnetic susceptibility of the band $ZrZn_2$ ferromagnetic subjected to pressures up to 42 kbar at temperatures down to 0.4 K. The resulting phase diagram of this substance differs substantially from the phase diagram known from previous works. In particular, it turned out that the superconducting phase transition does not disappear at the quantum critical point of the magnetic transition. The results of these researchers suggest that the phase diagram of $ZrZn_2$ contains a tetracritical point, which is an indication of the weakness of the interaction between the magnetic and superconducting order parameters.

As is known. quantum phase transitions take place at temperatures close to absolute zero, and the main parameters whose variation leads to the transition are the pressure, magnetic field, and structural disorder. Usually, it is the pressure that is used to lower the temperature of a continuous phase transition (usually between magnetic and nonmagnetic phases) almost to zero and to approach the quantum critical point. Despite the fact that the pressure values at which quantum critical phenomena are observed in the majority of known substances are not, by modern standards, very high (on the order of several dozen kilobars), the experimental study of such phenomena is extremely

complicated and requires a certain (rather high) level of knowledge of the methods and techniques of generating high pressures. The methodical problems encountered in building a facility capable of achieving conditions needed in studies of quantum phase transitions were discussed in the report "A facility for compressing helium and a hydrostatic chamber of the 'toroid' type for investigations at low temperatures". The authors of the report, Petrova, Sidorov and Stishov (all from IHPP), described a facility for generating high pressures in a medium of compressed helium, and a hydrostatic chamber of the toroid type used in low-temperature research. The facility for experiments in a medium of compressed helium consists of a high-pressure generator, a high-pressure chamber, and a cryostat. In addition to the standard elements, the high-pressure generator contains a reliable back-pressure valve which transforms the cyclic regime of the multiplier into a routine procedure and retains the pressure in the chamber even if some of the units of the generator fail. The high-pressure chamber is connected to the generator by a thin stainless steel capillary, which reduces the influx of heat to the cryostat. The chamber is housed in a hermetic holder, which can be moved inside a Dewar vessel, thus allowing one to economize on helium in experiments at temperatures above 4.2 K. Due to the special way in which the capillary in connected to the generator, the chamber can easily be lifted off the holder to replace the sample, to replace the gaskets, etc. The facility can be employed in research involving the study of the electrical, magnetic, and thermodynamic properties of matter at liquid-helium pressures up to 1.5 GPa and at temperatures down to 2 K or even lower. Specially designed anvils were used in the hydrostatic chamber of the toroid type. The sample is contained in a miniature Teflon capsule 2-mm high and 2.2 mm in diameter filled with liquid. The chamber is used for research at pressures up to 6 GPa in cryostats that allow the cooling of a cell that is 135-mm high and 53 mm in diameter.

O B Tsiok, L G Khvostantsev (both from IHPP) and A V Golubkov and I A Smirnov (both from PTI) in their report "The electron and lattice stages in a valence transition in SmTe under high hydrostatic pressure" presented the results of precise measurements of electrical resistivity, thermoelectric power, volume, and thermal conductivity of SmTe in conditions of true hydrostatic pressure at room temperature. High-quality stoichiometric and doped (n type, $n \sim 8 \times 10^{18}$ cm^{-3}) single-crystal samples were studied. It was found that the valence transition occurs in a sequence of stages in which the electron subsystem and the crystal lattice undergo transformations that take place under different pressures. In the initial stage of the transition there is observed metallization accompanied by anomalies in the kinetic coefficients; here, the pressure dependence of the volume deviates from the curve corresponding to the initial semiconducting phase only slightly. The next stage is characterized by a substantial change in the sample's volume (lattice collapse), but the electrical resistivity and the thermoelectric power cease to depend on pressure in this pressure range. In the final stage of the transition, the compressibility of the sample decreases and the electrical resistivity and thermoelectric power again begin to depend on pressure, and a state emerges in the sample that, according to all measured properties, corresponds to the 'gold' SmS phase. The authors of the report believe that their experimental results allow for a consistent description based on the exciton model with two types of excitonic excitation: 'ordinary shallow' excitons which play an important role at the beginning and end of the transition, and 'hard' excitons which correspond to the high-temperature resonance mode of oscillations and determine the behavior of the system in the maximum anharmonicity region (the maximum compressibility region).

On the whole, we must note that, as shown by the second seminar, the interest in this area of research has grown. The larger number of reports made it possible to cover a broader spectrum of problems related to various aspects of the physics of strongly correlated systems and quantum critical points. As usual, both experimental and theoretical works were presented at the seminar on an equal basis, which was conducive to a broad exchange of information between theoreticians and experimentalists and to raising the effectiveness of the discussion that took place. The success of the first two seminars gives hope that the seminar "Strongly correlated electron systems and quantum critical phenomena" will be held regularly.