Physics – Uspekhi **51** (2) 199 – 203 (2008)

CONFERENCES AND SYMPOSIA

PACS numbers: 01.10.Fv, 05.70.Fh, **75.40.–s**

Ongoing International conference on phase transitions and related critical and nonlinear phenomena in condensed media: special event held on the occasion of the 50th anniversary of the RAS Daghestan Science Center's Institute of Physics (12 – 15 September 2007, Makhachkala, Daghestan, RF)

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DOI: 10.1070/PU2008v051n02ABEH006520

Abstract. **A brief review is given of the results presented at the International conference "Phase transitions, critical and nonlinear phenomena in condensed media" that was held on 12 – 15 September 2007 at the RAS Daghestan Science Center on the occasion of the 50th anniversary of the Center's Institute of Physics and in the framework of which the VIII International seminar Magnetic phase transitions was conducted.**

The conference and the seminar were organized by the Division of Physical Sciences of the Russian Academy of Sciences (RAS), and the Magnetism section of the RAS Science Council on the Physics of Condensed Media, together with the Institute of Physics of the Daghestan Research Center of the RAS and Daghestan State University.

These scientific events were conducted with the active support of the Russian Academy of Sciences, the Russian Foundation for Basic Research, and the Dynasty Foundation of Noncommercial Programs.

Selected for the conference and seminar were 213 contributions from 19 cities of Russia and fourteen other countries, of which ten were assigned plenary status, 59 were for oral presentation, and 144 were for poster sessions. More than 200 participants contributed to the conference proceedings. The topics discussed covered practically every field in the physics of the condensed state that related in some way to phase transitions (PTs), critical phenomena (CP), and nonlinear phenomena.

The conference was organized into the following sections: Magnetic phase transitions, Numerical simulation of phase transitions and critical phenomena, Critical phenomena in liquids, Phase transitions and critical phenomena in ferroelectrics, High temperature superconductivity (HTSC), and liquids, and Phase transitions, nonlinear phenomena and chaos in condensed media. The opening ceremony and the festivities on the occasion of the 50th anniversary of the Institute of Physics of the RAS Daghestan Research Center took place on September 12.

The goal of the conference was to acquaint the participants with the latest achievements, the current status, and new ideas and approaches in the fields of phase transitions and critical and nonlinear phenomena in condensed media.

One of the central problems discussed at the conference was that of phase transitions in materials with strong electron correlations. The plenary contribution by Yu A Izyumov (The Institute of Metal Physics of UrO RAS, Ekaterinburg) presented an analysis of the electron structure and the main physical properties of strongly correlated systems that incorporate elements with unfilled 3d, 4d, and 5f shells. Such systems cover an enormous number of materials and compounds that manifest a great variety of phase transitions. The report showed that the low-energy physics of these compounds is described by three basic models: the Hubbard model, the sd-exchange model, and the Anderson periodic model in the situation where the energy U of the on-site Coulomb repulsion of electrons or the sd exchange energy J are of the order of the conduction band width W. In this case, the problem contains no small parameter and nonperturbative approaches are therefore required. The report presented one such approach, the dynamic mean field theory (DMFT). Many theoretical approaches used for describing strongly correlated systems encounter serious obstacles when applied to real systems. The situation greatly changed, however, after Metzner and Vollhardt suggested in 1989 to formally treat a system of strongly interacting electrons in a space with a higher dimension d. It was found that the mathematical equations describing the motion of electrons in the lattice are greatly simplified in the limit $d \to \infty$ and can be solved exactly for any interelectron coupling. It was also found that the results of calculations in this limit are close to the results of numerical calculations for the real space $d = 3$. The DMFT can therefore become a universal method of investigation of strongly correlated systems. In this theory, we neglect spatial correlations and account only dynamic correlations take into. The DMFT assumes a numerical calculation sequence that reduces the problem of the structure of the electron spectrum of systems of interacting lattice electrons to that of a single impurity center placed in an effective dynamic field of other electrons. Furthermore, there exist various generalizations of the DMFT, which to a certain higher- or lower-degree take

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Received 14 November 2007
Uspekhi Fizicheskikh Nauk **178** (2) 211 – 216 (2008)
DOI: 10.3367/UFNr.0178.200802j.0211
Translated by V Kisin; edited by A M Semikhatov

spatial correlations in the system, i.e., corrections of the order of $1/d$, into account. This allows studying the structure of the Fermi surface of strongly correlated systems. The speaker conclusively demonstrated, by considering the main classes of strongly correlated systems from a unified DMFT standpoint, that the DMFT theory currently offers the most universal method for studying such systems and provides quantitative agreement with experimental results.

The specifics of phase transitions and magnetic, thermal, and other physical properties of superlattices have attracted considerable interest in recent years. The first part of the talk by A K Murtazaev (Institute of Physics of the DNTs, RAS, Makhachkala) presented a review of theoretical and experimental research in phase transitions and critical phenomena in magnetic iron–vanadium superlattices $[Fe_2/V/Fe_3]_L$. An analysis of the critical properties of magnetic superlattices shows that the current situation is interesting and entangled, owing to contradicting experimental data. The values of certain critical exponents correspond to three-dimensional systems, while other exponents characterize the same systems as two-dimensional. The fact that [Fe/V] superlattices manifest critical exponents corresponding to three-dimensional systems is a sign of importance and the possibility of exchange interaction between iron layers across nonmagnetic vanadium layers. It was shown experimentally that when such a system is placed in a hydrogen atmosphere, hydrogen atoms penetrate the vanadium sublattice. This changes the thickness of the vanadium interlayer. The amount of the adsorbed hydrogen is a function of pressure in the hydrogen atmosphere that allows continuous variation of the distance between iron layers; this in turn causes a change in the characteristics of this interaction, from antiferromagnetic to ferromagnetic. Hence, the interlayer interaction can be reduced to zero at a certain hydrogen pressure. Therefore, these systems are an ideal subject for observing the transition from three-dimensional magnetism to two-dimensional, and then the reverse transition. We also note that critical exponents are highly sensitive parameters and their calculation allows finding with high accuracy not only the universality classes of critical behavior of these complex systems but also the conditions and specifics of the transitions (the crossover) from the 2D to 3D behavior. The report also presented results obtained by the Monte Carlo method on the basis of a three-dimensional xy-model that can be used for describing an entire class of iron–vanadium superlattices $[Fe_2/V_n]_L$. The Hamiltonian is given by

$$H = -\frac{1}{2}\sum_{i,j} J_{\|}(S_i^x S_j^x + S_i^y S_j^y) - \frac{1}{2}\sum_{i,k} J_{\perp}(S_i^x S_k^x + S_i^y S_k^y)\,, \qquad (1)$$

where the first sum accounts for the exchange interaction of each magnetic Fe atom with its nearest neighbors inside the layer, the second describes the interaction with one atom of the neighboring layer across the nonmagnetic vanadium interlayer, and S_i^x and S_i^y are projections of spin onto the x and y axes. The relation between the interlayer exchange $J_{\|}$ and the interlayer exchange $J_{\perp}$ depends on the distance between iron layers, which in turn depends on the amount of absorbed hydrogen in the vanadium layers. Cases were considered where the ratio $r = J_{\perp}/J_{\|}$ (it was an imposed parameter in these experiments) varied from $r = -1.0$ to $r = 1.0$.

To calculate critical exponents, the theory of finite-dimensional scaling was used and the critical temperatures were found using Binder cumulants. Among the main results, we note the observation that for $r = 1.0$, the model under consideration corresponds to the classical xy-model, and that the values of critical exponents reported by the authors of the talk coincide with high accuracy with the best data found for the xy-model by other techniques. A reduction in the parameter r results in a smooth variation of the values of critical exponents. The known scaling relations between critical exponents (for instance, the Rushbrooke relation) hold up to a certain threshold. But a fairly significant change in values of the exponents occurs at $r = 0.01$, which is simultaneously accompanied by violation of scaling relations. This gives the basis for assuming that in these systems, the value $r = 0.01$ is the boundary for the transition from three-dimensional to two-dimensional magnetism. It was also discovered that certain deviations are observed at $r = 0.01$ in the temperature dependence of thermodynamic parameters that are absent at larger values of r. Therefore, the value $r = 0.01$ can be assumed to be the threshold and the system can be regarded as quasi-two-dimensional at $r < 0.01$.

A considerably more complex and diverse situation is found in models of superlattices $[Fe_2/V/Fe_3]_L$. In these systems, the ferromagnetically ordered layers Fe_2 and Fe_3 also interact across a vanadium interlayer. The fact is, nevertheless, that the entire system can be regarded as built of three subsystems: the first subsystem comprises iron layers consisting of two monolayers of Fe_2; the second of two outer layers of Fe atoms in 'triple' layers of Fe_3; and the third of a monolayer of Fe atoms in triple Fe_3 layers. All three subsystems are in different conditions and phase transitions in them occur at different temperatures. Therefore, we are dealing with a system manifesting three phase transitions in the course of interaction between all the subsystems of which it consists. The report demonstrated specifics in the behavior of the model that describes this complex system. Thermodynamic parameters were studied as functions of the temperature and the field at different values of $r = J_{\perp}/J_{\|}$. A number of effects were observed resulting from the presence of three interacting subsystems in the system.

Traditionally, an important place is taken at these conferences by discussions of the results of investigations of phase transitions in systems with shape memory effects. V G Shavrov (RAS Institute of Radioelectronics, Moscow) and V D Buchel'nikov (Chelyabinsk State University, Chelyabinsk) discussed the properties of ferromagnetic Heusler alloys. These systems continue to attract attention as much as they did in the past because they not only possess the shape memory but also manifest the gigantic metallocaloric effect. What occurs in these alloys is a structural phase transition from a high-temperature cubic (austenite) phase to a low-temperature tetragonal (martensitic) phase, as well as a magnetic phase transition from the paramagnetic to the ferromagnetic phase. The structural and magnetic phase transitions coincide for certain alloy compositions; the result is a joint magneto-structural transition. Some Heusler alloys can have a structural phase transition that is accompanied by a magnetic transition from the ferromagnetic to the antiferromagnetic phase. In this case, a sequence of phase transitions occurs as the temperature decreases: paramagnetic cubic phase → ferromagnetic cubic phase → paramagnetic tetragonal phase → ferromagnetic tetragonal phase. The authors of these reports noticed that the increased interest in these alloys reflects a considerable number of anomalously pronounced effects. Observations revealed large strains induced by a magnetic field, the giant magnetocaloric effect, and the large magnetic resistance effect. By using the Landau phenomenological theory of phase transitions, phase diagrams of those Heusler alloys were theoretically investigated in which inversion of exchange interaction could be realized. It was shown that the shape of phase diagrams depends in such alloys on the signs and values of parameters of the Landau functional. The results obtained allow interpreting the rich variety of phase diagrams and the effects experimentally observed in Heusler alloys.

The fascination with shape memory alloys stems not only from their extremely rich menagerie of structural and magnetic phase transitions but also from the fact that most of these effects may find or have already found application in practical devices. These alloys may form a foundation of a new class of sensors and actuators. The prospect of using them as functional materials in micro- and nanomechanics, and also in medicine, is very promising.

Among the contributions that treated the purely theoretical aspects of studying phase transitions and critical phenomena, we must note the review talk by A I Sokolov (Saint Petersburg State Electrotechnical University (LETI), Saint Petersburg) and the report by S V Belim (Omsk State University, Omsk) offering original results. A I Sokolov threw new light on many aspects that reflect the effects of anisotropy on critical phenomena. Using the effect of cubic anisotropy as an example, he showed that the interaction between critical fluctuations in a system with anisotropy results not only in nontrivial values of critical exponents but also in qualitatively new physical effects arising in the system. Such effects were first discovered when the renormalization group method was applied to studying the critical behaviors of anisotropic systems. It was shown that in the absence of critical fluctuations, a crystal with cubic anisotropy may transform into a ferromagnetic state either as a result of a continuous phase transition or a first-order phase transition. Fluctuations of the order parameter in the immediate vicinity of T_c become anomalously large. How do they affect the characteristics of phase transitions? An analysis showed that the magnetic subsystem of a cubic crystal may become effectively isotropic in the critical area. This phenomenon, quite unexpected from the standpoint of the classical theory of phase transitions, is now referred to as 'isotropization.'

Another interesting effect is that if the initial anisotropy is sufficiently high as $T \to T_c$, then it continues to increase in approaching T_c, and therefore it max eventually switch the type of phase transition and a first-order phase transition may arise in the system. This phenomenon is known as fluctuation-induced instability or fluctuation destabilization of second-order phase transitions. A theoretical analysis showed that a collapse of a continuous phase transition is also possible at any anisotropy, arbitrarily weak, if certain specific interactions are taken into account, such as the magnetic dipole–dipole interaction. Furthermore, these specifics are especially well pronounced in systems with complex ordering patterns when the expansion of free energy contains many different invariants and, as a consequence, many independent coupling constants. The author of this report paid much attention to the aspect of reliability of the nontrivial predictions of the theory. He gave specific examples that brilliantly confirmed a number of predictions of the renormalization group theory and at the same time pointed to serious difficulties encountered by this powerful and efficient theory.

In his talk, S V Belim touched on a very complex aspect connected with how a free surface affects the manifestations and specific features of critical phenomena. The important factor is that processes of ordering on a free surface could occur at a temperature that differs from that at which the phase transition occurs in the bulk. There is a temperature range within which surface effects play the dominant role and are characterized by a specific set of critical exponents. Such systems have a very rich phase diagram with a multicritical point. Calculations carried out for homogeneous and disordered systems showed that a free surface affects the bulk critical behavior of both these types of system. We note that the results obtained with taking into account that fixed points of the renormalization group transformation shift due to the presence of free boundaries agree better with the results of Monte Carlo calculations than with those obtained assuming no influence of the surface on bulk critical exponents.

Nonlinear phenomena in condensed media constituted one of the central topics at this conference. Among the reports devoted to nonlinear phenomena in magnetic systems, the report by M A Shamsutdinov (Bashkirian State University, Ufa) deserves special attention. Aspects connected with the nonlinear dynamics of magnetization in magnetic films and single-domain particles in high-amplitude ac fields have been intensely studied in recent years. In fact, the problem lies in the fact that instabilities in oscillations of magnetization may arise at high amplitudes. The report by M A Shamsutdinov paid considerable attention to studying the conditions under which nonlinear oscillations of magnetization can be excited in single-domain particles by a high-frequency low-amplitude field. The difficulty of exciting oscillations of a sufficiently high amplitude by weak external factors consists precisely in the fact that the resonance is typically destroyed as the amplitude of oscillations increases. To sustain resonance conditions, the frequency of the dynamic system needs to be kept tuned to the frequency of the external factor. The phenomenon of automatic adjustment of the eigenfrequency of a nonlinear dynamic system to the frequency of an external factor is known as autoresonance (autophasing).

Autophasing in ferromagnetic materials remains poorly known both experimentally and theoretically. This report shows under what conditions nonlinear ferromagnetic resonance can be phase-locked. For this, it is necessary that the amplitude of the exciting field be higher than a certain threshold level required to transfer the system to the mode of nonlinear oscillations of magnetization. Also, the pumping amplitude must grow sufficiently fast so as not to allow the precession angle to decrease, that is, not to allow violation of the resonance condition owing to dissipation. It is thus shown that the autoresonance excitation of nonlinear oscillations of magnetization in single-domain ferromagnetic particles with zero dissipation is possible in two cases: when the resonance field slowly increases or when the frequency of the excitation field slowly decreases. If damping is nonzero, autoresonance survives if, in addition, the amplitude of the excitation ac field slowly increases. We note that the autoresonance excitation of nonlinear oscillations of magnetization at the frequency of the linear ferromagnetic resonance in an ac field is to occur if the resonance field slowly increases in time parabolically, while the ac field amplitude increases linearly.

A study of the properties of Josephson structures remains one of the topical and interesting problems in low-temperature solid state physics. The storage and processing of information as quanta of magnetic flux, RSFQ (Rapid Single

Flux Quantum Logic), and building a quantum computer in principle appear feasible by using such structures. This was discussed in the report of E V Matizen (Institute of Inorganic Chemistry of the Siberian Branch of RAS, Novosibirsk). The importance of studying such structures also lies in the fact that the phenomenon of the Josephson generation opens a possibility of creating sources of radio emission in the vacant niche of the frequency range of dozens and hundreds of MHz. Emission by single contacts becomes possible in regular lattices, which greatly increases the efficiency of such generators. A heterodyne receiver for the frequency 500 GHz to process signals of very low power ($\approx 10^{-13}$ W) was designed and successfully tested. The magnetic dynamics of Josephson lattices (*J*-lattices) that are the key element of the practical application of such structures was analyzed in a large number of theoretical publications. Experimental work with *J*-lattices is mostly limited to studying their current – voltage characteristics, but the behavior of the magnetic moment was considered in only a few papers. Since the behavior of the observed magnetic moment of *J*-lattices differs very much from its theoretical description, experimental studies of magnetization of real *J*-lattices were carried out. The authors are of the opinion that the existing differences between theoretical and experimental data stem from the fact that the theoretical analysis is based on simplified models and on equations that do not describe all of the important properties of Josephson contacts and the dynamic links between them. An investigation of lattices with SIS (superconductor – insulator – superconductor) contacts and those with SNS (superconductor – poor metal – superconductor) contacts showed that peaks of the magnetic moment on the magnetization curves of SIS- and SNS-lattices are observed, with a period in a field that corresponds to one magnetic flux quantum. At low temperatures, peaks in SIS-lattices become wider but at the same time random oscillations of the moment emerge, tied to the transition of the system to a special phase state: that of a 'self-organized criticality' with magnetic flux avalanches.The temperature of the transition of a lattice into the state of self-organized criticality corresponds to the area in which the depth of field penetration into the lattice is smaller than the lattice cell period. In SNS lattices, a considerable asymmetry of the hysteresis curve is observed.

The report presented by G E Norman (RAS Joint Institute for High Temperatures, Moscow) was devoted to phase transitions in metastable liquids and superheated and stretched crystals, studied by methods of molecular dynamics (MD), and caused much interest. The report analyzed the kinetics and dynamics of transformations that occur when metastable states become unstable. Attempts by the author at developing a theory of phase transitions of metastable states based on a molecular-dynamics experiment started with three main concepts. First, the so-called multiscale approach. When a phase transition is an object of direct simulation, one singles out 'elementary processes' of relaxation, of which the phase transition consists. Each of these elementary processes can be studied in individual MD experiments. Then theoretical 'assembling' of the obtained characteristics of individual elementary processes is carried out into a theory that would describe the process as a whole, and this allows going beyond the temporal and spatial bounds within which direct simulation is valid. Second, when 'elementary processes' are modeled, one considers thermodynamic paths along which relaxation evolves. Cases were reported in which relaxation occurs so rapidly that local equilibrium was disturbed and nonequilibrium distributions had to be found for various degrees of freedom. The report gave examples of phase diagrams with spinodals and paths of shockwave compression and aftershock decompression. Third, a number of reasons (such as divergence of particle trajectories) made it necessary to explicitly use the stochasticity of the MD method over times longer than the characteristic time of dynamic memory. The speaker gave results for phase transitions in four types of systems: an isotropic metastable liquid; anisotropic crystals; stretched crystals; and when the decay of one stretched homogeneous crystal results in restored stability and formation of another, stretched two-phase metastable state of the crystal. In all cases the authors discussed specific features, mechanisms of phase transitions, and the observation conditions.

The report by A M Askhabov (Institute of Geology of the Komi NTs UrO RAS, Syktyvkar) deserves special mention. It is for some time now that Askhabov has been developing a concept based on the assumption that there exist specific nanoclusters given the name 'quatarons.' The author hypothesized that the quatarons are a specific form of cluster-like self-organization of matter at the nanolevel and interprets them as pre-crystallization clusters. Quatarons are hollow and quasi-spherical and only exist in quasi-equilibrium conditions. As they reach a critical size, they are transformed into the embryo of a new phase. According to Askhabov's data, quatarons and quataron states of matter manifest certain features characteristic of living matter. The author presented the main ideas of the quataron concept of abiogenesis in which quatarons act as concentrators of the main biogenic elements. The key idea of the hypothesis is that quatarons are precursors of the simplest elements of living matter. The idea stemmed from the surprising coincidence of the sizes of cavities in quatarons and of each of the nitrogen-containing compounds (adenine, thymine, guanine, cytosine, and others) and phosphate groups. It is interesting to remark that this hypothesis practically excludes any low-probability and over-complicated processes and partly removes the problem of the very low probability of spontaneous organization of such complex biopolymers as RNA and DNA. The author emphasizes that his quataron hypothesis for the origin of life has much in common with current theories.

The concept being developed by D Yu Ivanov (Baltic State Technical University, Saint Petersburg) is of interest to experts in critical phenomena. In accordance with this concept, two crossovers must be observed in non-idealized systems as they approach a critical point. As the critical point becomes closer, the classical medium-field-driven behavior of the system changes to fluctuation-driven behavior. A question then arises of whether the behavior of a real system, not of an idealized one, would evolve — and if it would, then how — as it moves deeper into the fluctuation area, i.e. as $T \to T_c$. While the answer is obvious for idealized systems and, according to currently available theories, consists in stating that the type of critical behavior in the neighborhood of T_c can occur only once, for nonidealized systems the answer is far from trivial. As T_c is approached closer and fluctuations become larger, the susceptibility of the system increases. This means that susceptibility to such features of nonideal systems as impurities and defects, gravitational and electromagnetic fields, free surfaces and shear stresses, and so on also increases. Furthermore, the critical point is a point of reduced stability. Therefore, the critical behavior in the vicinity of T_c is extremely sensitive to perturbations of various physical natures. In view of this, it is logical to assume that it is inevitable that at some depth into the critical region, a moment occurs when fluctuations are deformed and then completely suppressed. Consequently, the system must execute a reverse transition (a crossover) from fluctuation-driven critical behavior to mean-field-driven behavior.

D Yu Ivanov presented interesting experimental data that are not covered by the current theory of critical phenomena. An analysis of these data shows that the familiar mean-field-driven behavior is not observed far from the critical temperature. He showed using a number of pure substances as examples that no transition from critical to mean-field-driven behavior is observed in a real experiment at any distance from the critical point in a sufficiently wide range of normalized densities. We note that the effective critical exponents β and γ have values that differ from both the classical and the Ising critical exponents. It is obvious in this case that even if the 'Ising' region exists in real pure liquids, it may occur only in an extremely narrow temperature range. Taking all these data into account may require certain corrections to the current theory of critical phenomena.

By tradition, these conferences devote considerable time to reports that discuss critical and thermophysical properties of liquid systems. Among the reports that presented interesting and original results, we can specially point to those by V G Martynets (Institute of Inorganic Chemistry SO RAS, Novosibirsk), V N Kartsev (Saratov State University, Saratov), G G Petrik (Institute of Geothermal Problems DNTs RAS, Makhachkala), A G Cherevko (Siberian State University of Telecommunications and Informatics, Novosibirsk), L M Radzhabova, E I Bezgomonova, G M Ataev (all three from the Physics Institute of DNTs RAS, Makhachkala), and a number of other reports. Looking at the field of phase transitions and critical phenomena as a whole, we can conclude that today's phase consists of careful research aimed at collecting and accumulating experimental data for different liquid systems. The center of gravity of these studies is now shifting toward complex liquids and to wider application of methods of numerical modeling.

As always at these conferences, young researchers from Ekaterinburg, Krasnoyarsk, Moscow, Ufa, Omsk, Syktyvkar, Chelyabinsk, and other Russian towns took active part. A considerable number of reports were presented by young scientists from the Physics Institute of the Daghestan Research Center of the RAS (DNTs RAS), Daghestan State University, and Daghestan State Pedagogical University. We specially mention interesting reports by young authors: Zh G Ibaev, V A Mutailamov, M K Ramazanov, A B Babaev, M A Magomedov, A G Gamzatov, L M Radzhabova, E I Bezgamanova (all from the Physics Institute of DNTs RAS, Makhachkala), S A Krinitsyna (Omsk State University, Omsk), B C Vlasov, L S Nosov (Syktyvkar State University, Syktyvkar), N I Piskunova (Sibirskii State University Aerospace University, Krasnoyarsk), and V V Stegailov (RAS Joint Institute for High Temperatures, Moscow).

The reports delivered by the younger generation of scientists were evidence of their sufficiently high professional level and demonstrated improvements in the influx of talented young men and women into science. It should be noted that the research by many young speakers was supported by grants provided by various foundations; this undoubtedly helps to attract young people to science.

As has become a tradition, the conference was organized in such a way as to facilitate close communication between the young and the famous scientists. This brief review of a selection of reports presented at the conference and the seminar characterizes the main subjects and problems discussed during these gatherings.

An analysis of the results sent to the conference and the seminar demonstrates that in recent years, we have witnessed a stable tendency to intense progress in many fields of the current physics of phase transitions and critical phenomena. Many experimental results were obtained using modern, often very expensive, equipment. Fields of research stemming from nanophysics and modern computational physics are rapidly expanding. In practically every field we find results at world-class levels. The Organizing Committee prepared an interesting cultural program for the participants, including a trip to high-altitude Gunib and to Derbent, one of the oldest towns of Russia, and a visit to vineyards. Every detail of the programs prepared for the Conference and the seminar were implemented.