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Phase transitions and critical phenomena in condensed media

Third International Workshop "Magnetic Phase Transitions" dedicated to the memory of Academician A S Borovik-Romanov (8 – 11 September 1998, Makhachkala, Republic of Dagestan, Russia)

An International Conference *Phase Transitions and Critical Phenomena in Condensed Media* and, within its framework, the Third International Workshop *Magnetic Phase Transitions*, dedicated to the memory of Academician A S Borovik-Romanov, were held in Makhachkala, Russia, on September 8 – 11, 1998 at the Physics Institute of the Dagestan Scientific Center of the Russian Academy of Sciences (RAS).

The two previous (All-Union) workshops on magnetic phase transitions and critical phenomena were also held in Makhachkala, in 1984 and 1989, and attracted much interest.

The latest conference and workshop were arranged by the Division of General Physics and Astronomy, RAS and the Academy's research council on the problem "Magnetism" jointly with the Physics Institute of the Dagestan Scientific Center, RAS and the Dagestan State University.

The conference and workshop had the support of the Ministry of Science and Technology of the Russian Federation and the Russian Foundation for Basic Research. More than 100 people from four CIS countries and other foreign countries did participate in the conference and workshop. Fifteen reports were delivered at plenary sessions. In addition, there were 30 oral reports and 71 posters.

The topics of the conference embraced practically all aspects of the physics of condensed media related in one way or another to phase transitions and critical phenomena. The conference was divided into the following sections: magnetic critical phenomena, critical phenomena in ferroelectrics, critical phenomena and phase transitions in high-T_c superconductors and *n*-type semiconductors, critical phenomena in liquids, computer simulations of phase transitions and critical phenomena, nonequilibrium phase transitions and chaos in condensed media, and relaxation phenomena in phase transitions.

The purpose of the conference was to acquaint the participants with the basic ideas and current state of research into phase transitions and critical phenomena in all areas of the physics of the condensed state and with the latest progress in these areas.

The first day of the conference coincided with a convention of Dagestan physicists, which founded a Dagestan branch of the Russian Physical Society. The elected chairman is I K Kamilov, Director of the Physics Institute of the Dagestan Scientific Center, RAS and a Corresponding Member of RAS.

The focus of the conference and workshop was the problem of magnetic phase transitions and critical phenomena. The considerable progress in this area must be attributed to the employment of ideas, contained in the hypothesis of scaling, of universality and the renormalization-group theory. Nevertheless, to this day there is no unified, stringent and consistent microscopic theory of continuous phase transitions. Many of the theoretical results obtained in recent years in this area spring from the use of methods of renormalization-group theory. In static critical phenomena the experimental and theoretical data tally very well and there is a fairly deep understanding of the phenomena. This cannot be said of dynamic critical phenomena, however. Here, both theoretical and experimental methods face considerable difficulties.

The report delivered by Kh K Aliev (Physics Institute of the Dagestan Scientific Center, RAS and the Dagestan State University, Makhachkala) surveyed the present state of research into dynamic critical phenomena in magnetically ordered crystals by ultrasonic methods and detailed the results of an experimental study of critical phenomena in dielectric materials (ferrites with the structure of spinel or garnet) and metallic (gadolinium) materials. Studies of the influence of a homogeneous external magnetic field on the propagation of ultrasonic waves near the transition temperature in gadolinium revealed a magnetic-field analog of the Landau – Khalatnikov relaxation mechanism in the paramagnetic phase. This has been substantiated by using dynamic scaling. Studies of the influence of dipole forces on the propagation of ultrasonic waves close to the Curie point in gadolinium have made it possible to establish the dipole character of the critical dynamics (normal dipole dynamics). The critical indices of the speed of propagation and the absorption of ultrasonic waves and of the relaxation time, and the dynamic critical exponent z have been determined.

The report delivered by V G Shavrov (Institute of Radioengineering Electronics, RAS, Moscow) with a demonstration of the effect of shape memory attracted much attention. The report generalized the results of theoretical and experimental studies of magnetic and structural phase transitions in ferromagnetic 'smart' compounds. It also discussed the possibility of a first-order magnetic phase transition of the order – disorder type and estimated the influence of magnetic field and pressure on the structural (martensite) phase transition temperature.

The report by V V Koledov (Institute of Radioengineering Electronics, RAS, Moscow) concerned the influence of a magnetic field on the formation of structural domains in $Ni_{2.19}Mn_{0.81}Ga$, a ferromagnetic substance with shape memory and nonstoichiometric composition. The report also presented the results of research into the influence of a magnetic field on the kinetics of the martensite transition.

In recent years the focus of theoretical study of phase transitions and critical phenomena has shifted to an examina-

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tion of more complex and realistic systems. In studies of this kind one must take into account numerous complicating factors in the Hamiltonian, ignored in first-order approximate models. Notable among these factors are anisotropy and impurities, the presence of multispin and dipole interactions, and the need to allow for lattice vibrations.

At present, Monte Carlo methods are being successfully used to study such systems. In accuracy, the critical parameters calculated for simple lattice models by these methods are in no way inferior to the best results obtained by other methods. In addition, Monte Carlo methods are rigorous from the mathematical viewpoint and contain none of the unproved concepts typical of other theoretical approaches. This was all pointed out in the report delivered by A K Murtazaev (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala). The report also presented results obtained when Monte Carlo methods were used to study the models of complex real magnetic materials. The basic statistical critical indices were calculated. Using data obtained from studying a model of the antiferromagnetic Cr_2O_3, it showed that although the values of the critical indices computed according to the theory of finite-dimensional scaling are in better agreement with theoretical and experimental results, an analysis of the same data through an approximation by traditional power-law functions makes it possible to extract extensive additional information. The report noted that for getting the complete picture of the critical behavior of complex models the results of Monte Carlo modelling must be analyzed in both ways. All the data from Monte Carlo studies were compared with both theoretical predictions and data from laboratory experiments. In view of the rate of development of computers and the serious difficulties facing theoretical approaches in studying complex systems, the methods of computational physics may be expected shortly to become one of the most effective, important and promising methods for studying such systems. This fact was noted during the debates.

The influence of magnetoelastic interactions on magnetic phase transitions was the subject of a report delivered by L N Kotov (Syktyvkar State University, Syktyvkar, Russia).

When it came to the purely theoretical aspects of research into phase transitions and critical phenomena, attention should be drawn to results presented in the report of A I Sokolov (Electrotechnical University, St. Petersburg), in which the renormalization-group approach was used to calculate the high-order effective coupling constants for the Ising and Heisenberg models.

Among the reports concerning critical phenomena and phase transitions in the high-T_c superconductors much interest and discussion were sparked by the report delivered by I K Kamilov (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala) "Ginzburg convective thermal conduction in superconductors". After explaining the physical idea underlying the appearance of convective heat transfer in superconductors, an idea first advanced by Academician V L Ginzburg a good half-century ago, the speaker noted that no reliable experimental confirmation of this phenomenon has yet been offered although small-scale anomalies have been spotted in the thermal conductivity of the high-T_c superconductors, which can be interpreted as a manifestation of the convective mechanism of heat transfer. The main difficulties here stem from the weakness of the effect itself and the low accuracy in measuring thermal conductivity, inherent in standard equipment. Moreover, the initial theoretical estimate of the contribution of convective thermal conductivity has proved to be overvalued. Nevertheless, there is an understanding of the need to continue research in this area by, among other things, doing measurements in a magnetic field, since in the high-T_c superconductors convective thermal conductivity may greatly exceed theoretical predictions. Such work continues at the Physics Institute of the Dagestan Scientific Center, RAS with the use of a sophisticated method of determining thermal conductivity (the a.c. calorimetry method) that makes it possible to do precision measurements at small temperature differential along the sample (~ 10 mK), which greatly increases the chances of detecting this phenomenon.

Many speakers detailed the results of studies of critical phenomena in liquids. Much interest was sparked by the reports by E T Shimanskaya (T Shevchenko Kiev State University, Ukraine) and È V Matizen (Institute of Inorganic Chemistry, Siberian Branch of the Russian Academy of Sciences, Novosibirsk), who pointed up the timeliness of experimental studies of liquid systems for further development of the theory of phase transitions and critical phenomena. The reports presented new results of studies into the asymptotic behavior of the order parameters of alternative Freon and binary gas mixtures in the broad vicinity of the critical point and the critical line of vaporization, and they defined the regions of scaling behavior of thermal properties and the crossover transition temperatures.

G V Stepanov (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala) surveyed the studies of thermal properties of liquids carried out at the Physics Institute. He called attention to current combined experimental and theoretical investigations of the properties (specific heat at constant volume, pVT-dependences, thermal conductivity, surface tension and visual investigations of critical phenomena) of complex thermodynamic systems over a wide range of state parameters including the critical. The speaker detailed the results of research into one-component liquids (water, carbon dioxide, alcohols and H-alkynes) and also binary (H-pentane – H-heptane, H-hexane – water) and ternary (H-hexane – water – H-propanol and H-decane – carbon dioxide – water) stratifiable systems and discussed the generalizing dependences of thermal properties on the number of carbon atoms in homologous series and the effect of specific intermolecular interactions (the hydrogen bond). This research enjoys the financial support of the Russian Foundation for Basic Research.

The conference showed a marked interest in the report delivered by S M Rasulov (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala), who elaborated a new method of using one experimental apparatus to study viscosity and the pVT properties simultaneously. The speaker discussed the results obtained for water – H-hexane, H-pentane, H-heptane and their mixtures and specified the excess viscosity near critical points and the critical amplitudes and indices.

Among the unresolved problems relating to critical phenomena in liquids the conference noted the need to determine the region in which the classical equation is valid and to find the transition (crossover) region extending from singular nonclassical, critical behavior to classical van der Waals behavior in complex thermodynamic systems.

The debates on the reports devoted to a study of critical phenomena in liquids show that at present there is intensive research into high-order critical phenomena (highest finite critical point, double critical point and triple critical point) in complex liquid systems and study of the influence of the individual characteristics of the components of liquid systems on the choice of the order parameter and the equation of the phase equilibrium curves near critical points. The applied aspects of the research conducted at the Physics Institute of the Dagestan Scientific Center, RAS into critical phenomena in liquid hydrocarbon systems were presented in the report by V A Mirskaya (co-authors A N Stepanov of 'Volgograd-NIPI-Neft', Volgograd, Russia and I K Karpov, Institute of Geochemistry of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk) devoted to the modelling of critical phenomena in oil fields and the diagnostics of critical conditions in transient-state oils. The report pointed out that one of the crucial problems of the modern geochemistry of oil and gas is to develop theoretically substantiated, reliable methods of forecasting and diagnosing phase-genetic types of hydrocarbon deposits and distribution zones of critical hydrocarbon systems.

Study of the evolutionary dynamics of the thermodynamic parameters has made it possible to establish empirically the principal laws governing their influence on the critical properties of stratified fluids and their relation to thermobaric and other conditions. This opened the door to the first reliable classification of equilibrium state types and enabled predicting the development of phase stratification, azeotropism and some other processes that take place in the subcritical and above-critical regions in natural oil- and gas-bearing systems.

Some interesting results were detailed in reports that investigated critical phenomena and cooperative self-organizing processes in semiconducting materials.

A semiconducting crystal is a complex dynamical system in which such electrical instabilities as current cutoff, switching between conducting and nonconducting states, and spontaneous oscillations of current or voltage can be observed. Such phenomena occur owing to a strong electric field, irradiance or injection, and the semiconductor transits into a state far from thermodynamic equilibrium, in which spatial and temporal structures, i.e. issues of cooperative self-organizing processes similar to phase transitions, form spontaneously.

The considerable interest in these phenomena from the standpoint of nonequilibrium transitions stems from the fact that they are the basis of the functioning of several important semiconducting devices, and semiconductors themselves are the most suitable model systems for studying complex nonlinear dynamics, turbulence and self-organizing processes with higher spatial and temporal resolution than other (say, hydrodynamic) systems. Until recently most studies in this area of research were carried out in semiconductors with one type of carriers and under the action of only one external parameter. K M Aliev (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala) in his report detailed the results of using two types of carriers (electron – hole, electron – phonon, and hole – phonon) in an electron – hole plasma or in piezoelectric semiconductors in a two-parameter space (electric and magnetic fields, electric field and irradiance, and electric field and temperature). Hence the novelty and timeliness of these investigations.

The conference heard a report from V Z Zhokhov, I K Kamilov and A K Murtazaev (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala) entitled "The order – disorder – order phase transition in the conditions of sonic instability in tellurium crystals". The report noted that when supersonic drift of current carriers occurs in tellurium, order – disorder – order phase transitions manifest themselves, as the electric and magnetic fields increase, in a successive transformation of simple periodic current oscillations through bifurcations of frequency doubling into chaotic oscillations. Depending on the parameters and size of the tellurium samples, the temporal period changes dramatically, with the chaotic current oscillations becoming regular, almost periodic, oscillations. The experimental data obtained and the proposed theoretical mechanism of the development of dynamic chaos in electronic systems are timely, contributing to the further advancement of nonlinear acoustoelectronics. The suggested system with a strong acoustoelectronic interaction in electric and magnetic fields can be used to devise a new generation of controllable acoustoelectronic instruments, say, stochastic oscillators and current stabilizers.

The participants of the conference also heard a report by A A Stepurenko (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala) entitled "Autosolitons in InSb in a magnetic field".

Autosolitons constitute localized areas of enhanced temperature with a large gradient of the order of 3.5×10^5 K cm^{-1}. In a longitudinal magnetic field, owing to the Nernst – Ettingshausen effect, there appears in the autosoliton area an odd transverse potential difference whose field shifts the moving autosoliton to the denser and hotter region of the electron – hole plasma or to the region of less density and lower temperature, depending on the direction of the magnetic field. As a result, the change in the mobility and temperature ratios of electrons and holes leads to a variation in the phase velocity of the autosolitons and, consequently, to a change in the frequency of current oscillations in the sample.

Experimental studies of moving autosolitons in indium antimonide (InSb) showed that a fairly weak longitudinal magnetic field ($\sim 10^4$ A m^{-1}) provokes considerable change in the velocity of their movement in samples and gives rise to an appreciable redistribution of their electric field. This is the first time that experimental studies of the behavior of a dissipative structure, in particular, autosolitons in InSb in a magnetic field have been made. It is high time to study the behavior of longitudinal autosolitons in a magnetic field experimentally. The speaker noted the desirability of comparing the results of experiments with theoretical predictions relating to the behavior of dissipative structures in a magnetic field but added that there has been no such experiments as yet.

The report delivered by A M Askhabov (Geological Institute of the Komi Scientific Center of the Ural Branch of the Russian Academy of Sciences, Syktyvkar) deserves special mention for its suggested concept of self-organized substances, according to which the emergence and stable existence of atomic formations in the intermediate state between ordered and disordered ones in the form of nanometer-sized quatarons (a term used by the speaker to denote clusters in the 'latent' transition phase). The report is of interest for its interpretation of a wide range of critical phenomena linked to phase transitions in condensed media and also for a controllable synthesis of film and bulk cluster materials, or 'quatarites' (the speaker's term).

What distinguishes this conference was the great number of young scientific researchers involved, largely post-graduate students (Physics Institute of the Dagestan Scientific Center, RAS, Bashkir State University, Dagestan State

University, Dagestan State Pedagogical University, and other institutions). Interesting reports were delivered by, among others, K Sh Khizriev (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala), A R Mukhutdinova (Bashkir State University, Ufa, Russia), A A Aliverdiev (Physics Institute of the Dagestan Scientific Center, RAS, Makhachkala), and S A Eremin (Dagestan State University, Makhachkala). Participation in international forums of this kind is a good school of science for young researchers, offering the opportunity to become acquainted with the latest achievements and the results of research in the given subject.

Even though many wishing to take part were unable to do so for various reasons, the conference and workshop were a success. An analysis of the results reported shows that despite the disastrous financial state of fundamental science, some areas of the physics of phase transitions and critical phenomena in condensed media are developing vigorously. In practically all sections of the conference and workshop programs, the results meet world standards. It is most encouraging that the young people continue to turn to science and work at a sufficiently high scientific level.

The conference and workshop program was carried out to the letter.

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