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A joint scientific session of the Physical Sciences Division of the Russian Academy of Sciences (RAS) and the Joint Physical Society of the Russian Federation was held on September 25, 2002 in the Conference hall of the P N Lebedev Physics Institute, RAS.

The following reports were presented at the session:

(1) **Mezhov-Deglin L P** (Institute of Solid State Physics, RAS, Chernogolovka, Moscow Region) "Low-temperature physics under microgravity. Findings of the Chernogolovka Workshop 2002";

(2) **Nesvizhevskiĭ V V** (Laue – Langevin Institute, Grenoble, France) "Quantum states of neutrons in a gravitational field and the interaction of neutrons with nanoparticles";

(3) **Stepanov A V** (Central (Pulkovo) Astronomical Observatory, RAS, St.-Petersburg) "On the nature of radio emission from stars of late spectral type".

An abridged version of the reports is given below.

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Low-temperature physics under microgravity. Findings of the Chernogolovka Workshop 2002

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The Third International Workshop on Low-Temperature Physics in Microgravity Environment (Chernogolovka Workshop 2002, or briefly CWS-2002) was held on August 12 – 18, 2002 in Chernogolovka, Moscow region, Russia. According to tradition, CWS-2002 was included in the list of satellite conferences and workshops devoted to a rapidly developing area of research in low-temperature physics that accompany the International Conferences on Low-Temperature Physics held once every three years (the last one, LT-23, was held in Hiroshima, Japan on August 20 – 27, 2002).

The participants of the workshop were 120 scientists from 10 countries: Russia, Ukraine, USA, Finland, Kazakhstan, Denmark, France, Great Britain, Japan, and Georgia. They represented the national space agencies of Russia, Ukraine, USA, and Japan as well as various institutions of the academies of sciences and universities of several countries that conducted research in the area of low-temperature physics and technology and were interested in experiments carried out on board space vehicles. Seventy-two reports were delivered at the workshop, with the abstracts published in Ref. [1]. The Proceedings of the CWS-2002 will appear in a special issue of the journal *Low Temperature Physics* in the middle of 2003.

At the opening session, both the Chairman of the Workshop, Yu A Osip'yan, who is the Head of the Section of the Space Materials Science of the Space Council of the Russian Academy of Sciences, and the representative of the Rosaviakosmos Agency, Yu E Levitskiĭ, noted that in the 45 years since the launching of the Earth's first artificial satellite from Baikonur, the main Soviet launching site, space engineering and technologies have firmly established themselves in the life of modern society (satellite communications and TV, meteorological services and navigation, to name just some areas). The use of the achievements of modern science in space engineering leads to a broadening of the area of practical applications of space vehicles, which in turn stimulates new basic research on board space vehicles. At the same time, the high cost of conducting experiments in outer space suggests the need to develop a state-sponsored multistage system of selecting the proper experiments on a competitive basis, a system that in the initial stages would support a rather wide variety of ground experiments that would form the basis necessary for future selection of the most important and well-prepared in-flight experiments. All this must be taken into account in the long-term planning of research on board a space apparatus.

Notice that progress in space research is in many ways related to the broad introduction of cryogenic technology. As is known (see Ref. [2]), cryogenic liquids, primarily liquid oxygen and hydrogen, serve as fuel elements for spacecraft engines, while cooled detectors and electronic devices make it possible to increase the sensitivity and resolution of instrumentation by several orders of magnitude and thus realize the advantages of using long-term scientific research on orbital stations in conditions that cannot be maintained in ground-based experiments. For instance, the Infrared Space Observatory (ISO), which was placed in highly elliptic orbit by the European Space Agency (ESA) in 1995 and operated successfully up to the middle of 1998, was built around a 2200-litre cryostat filled prior to launch by superfluid helium II at 1.8 K. A set of cooled semiconductor resistors with operating temperatures in the 1.8 – 10-K range served as detectors on the ISO. The detectors used in modern X-ray spectrometers operate at temperatures as low as 65 mK [2].

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In the coming two years, the building of the multipurpose International Space Station (ISS), which includes, among other things, the large-sized Russian Research Segment (RS ISS), will have to be completed. Atomic clocks that use atoms of metals cooled by laser techniques to $10^{-2}-10^{-3}$ μK will be installed aboard the ISS in 2005 – 2007. This will make it possible to raise the relative resolution by several orders of magnitude (from 10^{-14} to 10^{-17}) in measuring short (~ 1 s) time intervals [3]. The programs of fundamental research that can be carried out aboard the ISS and re-entry space vehicles are being developed under the auspices of the Rosaviakosmos Agency, the national space agencies of the United States, the European Union, Japan, China, Canada, and other countries. A discussion about the results of the experiments conducted in orbit and of the plans for arranging novel investigations with a large segment of the scientific community, including researchers specializing in the given area of science and young scientists, is, undoubtedly, conducive to a more effective selection of the proper experiments and will attract new research workers. This constituted one of the principal tasks of the Third International Workshop on Low-Temperature Physics in Microgravity Environment.

The topics of all the reports given at CWS-2002 can be divided roughly into six groups:

(i) The major areas of low-temperature physical research in outer space; planning future fundamental research and building a technological basis needed for low-temperature experiments aboard the International Space Station.

(ii) Modeling of heat exchange processes at the liquid helium – solid interface in a microgravity environment.

(iii) Nonlinear waves in the bulk and on the surface of quantum liquids. Special features of the growth of helium crystals and phenomena on the surface of solid helium.

(iv) Nanocluster condensates in superfluid helium.

(v) Cryolayers and cryocrystals.

(vi) Ultracold atoms and particles, and Bose – Einstein condensation.

A discussion of the reports of most interest to the general public now follows.

1. Detailed reports on the results of outer space experiments conducted during the last decade under the auspices of NASA and the plans of using the International Space Station for fundamental physics research in the next five years were presented by Israelsson [3], Pensinger [4], and Strayer et al. [5]. Three series of experiments, in 1985, 1992, and 1997, have been conducted so far. These experiments studied the kinetic phenomena in superfluid helium near the point T_λ of phase transition from the superfluid state to the normal state. The experimenters studied, among other things, the behavior of the heat capacity of superfluid helium close to T_λ (at a distance of 10^{-9} K from the transition point in equilibrium conditions), thus refining the values of the parameters (critical exponents) of the theory of second-order phase transitions, and investigated the effect of pore size on the shift of the transition point in He II filling a fine-pored sample. Note that in a land-based laboratory, the pressure gradient in a column of superfluid helium 1 cm high leads, because of the Earth's gravitational field, to a 10^{-6} K shift in T_λ compared to the equilibrium value, and when studying thin layers we must take into account the effect of the interaction between the fluid and the walls, i.e., measurements in a microgravity environment have made it possible to move into the temperature region near T_λ, inaccessible in ground experiments. To ensure the required high resolution in temperature at a level of roughly 1×10^{-10} K, samples of paramagnetic salt were used as thermometers, whose susceptibility was measured by specially fabricated high-resolution superconducting quantum interferometer devices (SQUIDs). The employment of such high-resolution devices in conjunction with the accumulated experience of LT investigations in orbit makes it possible to expand the limits of future cosmic experiments.

The plans of NASA's fundamental research that will be carried out aboard the ISS in the next five years include experiments in low-temperature physics and atomic physics, which will begin in 2005 and will be continued in 2007, and studies into gravitational physics, with the beginning of such experiments planned for 2007. To perform low-temperature and gravitation studies, the external block of the Japanese research module on the ISS must be equipped with a specially designed low-temperature device known as the Low-Temperature Microgravity Physics Facility (LTMPF), which is currently being ground-tested at the Jet Propulsion Laboratory (JPL) at Pasadena, CA. The LTMPF consists of a 180-litre Dewar vessel with superfluid helium, the electronic equipment needed for measuring and monitoring the temperature, pressure, and level of the liquid helium, etc. in the Dewar vessel and for interfacing with the external radiation pickups and the accelerometers (the first block), and two blocks of control instrumentation, including the SQUID magnetometers for precision measurements of the induction produced by the magnetic thermometers. All this equipment will be used to conduct two independent experiments involving a couple of low-temperature inserts mounted inside the Dewar vessel on special pillars attached to the end faces of the cylindrical Dewar vessel. Each insert can be employed for conducting the main experiment and, if there is enough time, for one or two additional experiments.

According to the research schedule, experiments involving the LTMPF will start in the second half of 2005. The Dewar vessel will be filled with helium and cooled to 1.7 K just before launch time. It will operate in orbit for about 4.5 months, and then the facility will be returned to Earth. The plan is to send it into orbit again after 16 to 22 months on Earth.

The first two low-temperature experiments aboard the ISS will be devoted to studies of nonequilibrium phenomena near the phase transition point: (a) the critical phenomena near T_λ in He II (or critical dynamics in microgravity, DYNAMX), which amounts to studying the behavior of thermal conductivity near the superfluid liquid–normal liquid interface, where nonlinear phenomena are essential (minimum acceleration is needed to reduce pressure variations along the column of fluid), and (b) thermodynamic measurements near the liquid – gas critical point in ^{3}He (or microgravity scaling theory experiment, MISTE), which amounts to determining the critical exponents in the immediate vicinity of the critical point $T_{\rm cr}$. Additional experiments in this series will include measuring the heat capacity of He II near T_λ at a constant heat flux (or capacity at constant Q, CQ) and studying the shape of the liquid – vapor coexistence curve near $T_{\rm cr}$ in ^{3}He (or the coexistence curve experiment, COEX).

The second series of experiments in low-temperature physics on the LTMPF includes (a) the study of boundary phenomena in He II near T_λ (or boundary effects near the superfluid transition, BEST), which amounts to studying the properties of the superfluid in quasi-one-dimensional and three-dimensional pores, verifying the dynamic scaling theory, and studying the critical and transport phenomena in pores, and (b) experiments with a highly stable superconducting microwave oscillator (SUMO), which boil down to studying the interaction of bodies of different masses at small distances. The results of these investigations may be of interest in connection with refining modern ideas in the special and general theories of relativity, and the device itself can be used in further experiments with an atomic clock in the ISS orbit. Competitive selection of the most promising projects of additional experiments will be continued.

In 2005, an installation for experiments with ultracold atoms decelerated by the laser cooling method (or laser cooled atom physics, LCAP) will be built near the LTMPF. The accompanying instrumentation for this installation will be designed in such a way that a broad range of experiments and, in the first place, prolonged (more than one year) experiments in the area of gravitational physics can be conducted with the help of highly stable atomic clocks (or primary atomic clock in space, PARCS). The initiation of PARCS in the second half of 2005 will make it possible to increase the accuracy of measuring time intervals by one to two orders of magnitude compared to the existing accuracy (the expected temporal resolution will increase to 10^{-16} s) and to begin experiments in verifying Einstein's hypothesis concerning the invariance of time by comparing the operating frequencies of different clocks at diverse sections of the orbit. By the end of 2007, atomic clocks with rubidium atoms should be set up aboard the ISS (or rubidium atomic clock experiment, RACE). It is assumed that this will increase the time resolution by a factor of 10 compared to PARCS and thus will broaden significantly the field of application of atomic clocks in fundamental research.

NASA's plans also include building a condensed state laboratory aboard the ISS (or Condensate Laboratory Aboard the Space Station, CLASS), which will be used to cool atoms to temperatures much lower than 10^{-9} K and to observe Bose – Einstein condensation (BEC) in solutions of atomic gases under weakened gravitation. Next, using the cooled rubidium and cesium atoms as test bodies, one can attempt to verify the Einstein equivalence principle of the gravitating and inert masses (or quantum interferometer test of equivalence, QuITE). The competition among projects of additional experiments in the area of atomic and gravitational physics that will use the above facilities will be continued in 2003.

According to Okuda et al. [6], Japan's space agency NASDA is also selecting on a competitive basis applications for conducting low-temperature studies aboard the ISS. The list of the accepted applications includes the following projects: *Studies of nonequilibrium effects near the critical point*, A Onuki, Kyoto University; *Nonlinear dynamics of the nonequilibrium open system under control of laser*, K Yoshikawa, Kyoto University; *Basic research on crystal growth and surface physics of quantum crystals under microgravity*, Y Okuda, Tokyo Institute of Technology; *Instability of shear flow in a liquid near the critical point*, A Onuki, Osaka Prefecture University; *Variation principle for nonequilibrium reaction-diffusion systems under gravity*, K Kitahara, International Christian University, and *Structure of particulate layer under microgravity*, K Nakamura, Kyoto University.

The research plans for low-temperature physics and cryogenic technology investigations on board the Russian Segment of the ISS were presented at the workshop by M M Tsymbalyuk (see Ref. [7] and Table 1) and V A Shuvalov (see Ref. [8]), representatives of the Central Research Institute of Mechanical Engineering (CRIME, or TsNIIMASh in Russian) and the Rosaviakosmos Agency, and in the report of Bondarenko et al. [9], the representatives of the Ukrainian space agency. Note at once that the schedule for the in-flight experiments aboard the RS ISS has yet to be worked out and that the plans are still being discussed, so that the list of projects in Table 1 may change considerably. For instance, the possibility of arranging the series of experiments included in the projects 'Cryocomplex', 'Boiling', and 'Unity' presupposes a fairly large consumption of liquid helium in orbit and largely depends on the general concept of organization of low-temperature research on board the RS ISS.

The 'Cryocomplex' project, whose outline was discussed in the report by Buskin et al. [8], envisages the installment of three stationary helium-filled Dewar vessels outside the living quarters of the RS ISS. They are needed for long-term measurements at several temperature levels and will be connected to a system that ensures the transfer of liquid helium and the collection, storage, and liquefaction of the cold gas, i.e., the goal is to build on board the RS ISS a self-contained cryogenic facility capable of supplying liquid helium for three different experiments conducted simultaneously, including experiments in heat and mass transfer and in the dynamics of the formation and motion of gas bubbles in liquid helium. The 'Boiling' project, which is being developed under the aegis of the Ukrainian space agency [7, 9], envisages the study of boiling processes in a rotating Dewar vessel with a view to investigating the special features of heat transfer at the liquid helium–solid wall interface in conditions of weakened gravitation under accelerations amounting to $(10^{-2} - 10^{-6})g$.

What unites the 'Helium' and 'Wave' projects is the posing of the problem of computer simulation and experimental studies of the heat and mass transfer processes within the volume of a freely boiling liquid (liquid helium or nitrogen) and the phenomena that occur at the cryogenic liquid – solid wall interface in a microgravity environment (boiling mechanisms, growth of bubbles, and the peculiarities of heat transfer in a two-phase system). Some of these problems were discussed in the reports of Kryukov (see Ref. [10]) and Polezhaev (see Ref. [11]). Their experimental study is also needed in order to solve the practical problems that emerge when cryogenic liquids are used in spacecraft engines and in onboard equipment cooling systems.

The 'Soliton' project envisages a series of static and dynamic studies of the phenomena on the charged surface of liquid hydrogen in a cell of finite size. As noted in Levchenko's report (see Ref. [12]), the onground experiments conducted at the Institute of Solid State Physics, RAS (Chernogolovka) have revealed the presence of what is known as reconstruction of the shape of a fluid surface: as the strength of the external stretching electric field exceeds a certain critical value E_{cr} on an initially flat, uniformly charged surface of liquid hydrogen, there forms a hump (a solitary standing wave) whose height increases with the field strength. Theoretical calculations showed that the observed reconstruction of the charged flat surface can be described in terms of the theory of second-order phase transitions, where the stretching electric field, rather than the temperature (as in ordinary circumstances), acts as the external force. Reconstruction is observed in conditions where the applied electric field balances out the gravitational field. The passage to measurements in a microgravity environ-

Table 1. Research plans on board the RS ISS.

Name of experiment	Intention of experiment	Expected participants
‘Helium’	Fundamental research into the helium interface	Moscow Power Engineering Institute (MPEI), S P Korolyov ‘Energy’ Rocket-Space Corporation (RSC ‘Energy’), Yu A Gagarin Russian State Research and Testing Center of Cosmonaut Crew Training (RSRTC CCT), and other institutions
‘Wave-ZMKS’	Research in the field of heat and mass transfer and hydrodynamics in a tank with a cryogenic liquid	M V Keldysh Research Center, RSC ‘Energy’, and RSRTC CCT
‘Boiling’ group of space experiments	Fundamental research in LT physics and perfecting methods and means of effective and safe cryogenic experiments within the RS ISS infrastructure	CRIME, MPEI, Russian Research Centre ‘Kurchatov Institute’, P L Kapitza Institute for Physical Problems of RAS, Joint Institute for High Temperatures of RAS, P N Lebedev Physics Institute of RAS (FIAN), and the Institute of Low-Temperature Physics and Engineering of the Ukrainian National Academy of Sciences
‘Unity’	Fundamental and applied research in the field of LT physics and technology	CRIME, Nuclear Physics Research Institute (NPRI) of Moscow State University, RSC ‘Energy’, and other institutions
‘Cryocomplex’	Implementation of the concept of a united complex of cryogenic equipments for conducting several experiments aboard the RS ISS simultaneously	CRIME, MPEI, RSC ‘Energy’, and other institutions
‘Soliton’	Fundamental research into nonlinear phenomena on the surface of condensed hydrogen	Institute of Solid State Physics of RAS, RSC ‘Energy’, RSRTC CCT, and other institutions
‘Submillimetron’	Fundamental astrophysical research in the submillimeter range of electromagnetic waves, inaccessible from Earth, with a cryogenic telescope	Astro-Space Center of FIAN, RSC ‘Energy’, RSRTC CCT, and international collaboration
‘AMS’	Implementation of fundamental physical and astrophysical research involving an alpha-magnetic spectrometer with a superconducting magnetic system	NPRI, RRC ‘Kurchatov Institute’, and international collaboration
‘BSMK’	Working out processes for drying biological preparations involving an onboard sublimation-freezing complex (BSMK in Russian)	‘Biopreparat’ company, ‘Biokhimmash’ company, RSC ‘Energy’, and RSRTC CCT
‘Cryoconservation’	Working out methods and technical means for cryogenic conservation of biological preparations on board RS ISS	RSC ‘Energy’, RSRTC CCT, ‘Biokhimmash’ company, and ‘Biopreparat’ company
‘Crystallizer’	Study of physical processes of protein crystallization with the use of cryogenic technological media	CRIME, and the Institute of Crystallography of RAS
‘Poligon-1’	Working out methods for determining the degree of air and ground pollution with the use of cryogenic IR gas analyzers	CRIME, and other institutions

ment, where in a finite-size cell the interaction between the fluid and the walls of the vessel has to play an important role, may dramatically change the character of the observed phenomena. Another indication of this is the results of test investigations into the evolution of the shape of the surface of a liquid hydrogen charged film suspended from the surface of the upper plate of a horizontally positioned plane capacitor in which the electric and gravitational forces act in the same direction.

If we apply an alternating electric field in addition to the constant field, waves appear on the fluid surface. Laboratory experiments have demonstrated the possibility of weak wave turbulence setting in on the surface of liquid hydrogen, provided that excitation levels are high. More than that, the researchers were able to observe the high-frequency edge of the Kolmogorov vibrational spectrum, where the wave regime of energy transfer is replaced by viscous damping. The reconstruction of the surface markedly changes the shape of the dispersion curve $\omega(\varkappa)$ which describes the frequency dependence of the waves propagating along the surface of liquid hydrogen on their wave vector, which in turn strongly affects the spectrum of the nonlinear waves generated on the surface of the liquid by the alternating force. All this suggests that carrying out an experiment with a view to studying nonlinear waves on the liquid hydrogen charged surface on board the ISS will significantly broaden the existing ideas concerning the physics of nonlinear phenomena in condensed systems; in particular, it will lead to a better understanding of the propagation of capillary waves on the fluid surface in a microgravity environment.

The ‘Submillimetron’ and ‘AMS’ projects envisage broad international cooperation of Russian and foreign scientists collaborating with ESA and NASA. In the first project, superconducting radiation detectors and electronic equipment will be manufactured by foreign scientists, while the remaining equipment and launching of the telescope will be done by Russia. In the second project, it is assumed that Russia will build only the superconducting magnetic system of the alpha-spectrometer. A variant of the magnetic system being developed in the Russian Research Centre ‘Kurchatov Institute’ was discussed at a workshop in the report of N A Chernoplekov.

In the projects listed in the four lower lines of Table 1, the cryogenic equipment will be used to provide the necessary temperature conditions for experiments in the biology and physics of the Earth.

2. As can be seen in the above sections, the topics of the reports presented at CWS-2002 are much broader than the list of the topics of research in LT physics included in the plans of the Rosaviakosmos Agency, NASA, and other national space agencies for the next five years. The most promising areas of research that can be recommended for implementation and could be included in the list of ground experiments sponsored by national space agencies are (a) the study of properties of cryolayers that form as a result of condensation of the substance being studied onto a cold substrate (this problem was discussed in the reports by Strzhemechny [13] and Drobyshev et al. [14]), and (b) the recently opened up field of research involving the study of the properties of extrinsic nanocluster condensates (gels) that form as a result of condensation of a stream of gaseous He with an admixture of vapor of the investigated substance in superfluid He II (the reports by Khmelenko et al. [15], Popov et al. [16], and Mezhov-Deglin and Kokotin [17]). The mechanism of formation of impurity clusters in a cold helium jet, the interaction of these clusters with each other and with the surrounding medium at temperatures near 1 K, the structure and properties of porous nanocluster systems (gels whose dispersive system, or frame, is formed by impurity clusters surrounded by a layer of solidified He, while liquid He is the disperse medium), and the effect of the gravity environment on the properties of the forming condensates (ground-based measurements and experiments in a microgravity environment) — the solution of all these problems is important not only for modern materials science, whose constituent part is the physics of a condensed state, but also for astrophysics and cosmology (dust clouds in outer space at a temperature of about 3 K, ice in outer space, etc.). There are reasons to believe that impurity gels in superfluid He II can be used to accumulate and store free radicals (low-temperature fuel cells [15]) and ultracold neutrons. The report by Nesvizhevsky et al. [18] at the closing session was devoted to the advances in the physics of ultracold neutrons.

The CWS-2002 workshop was organized by the Institute of Solid State Physics, RAS and the Section of the Space Materials Science of the Space Council of RAS and was supported financially by the Ministry of Industry and Science of the Russian Federation, the Russian Foundation for Basic Research, the Rosaviakosmos Agency and also by NASA and INTAS (grant 02-MO-263). A round table conference for the participants of the projects supported by INTAS in 2001 and 2002 was held within the framework of the workshop. The members of the local committee M Yu Brazhnikov, V B Efimov, A M Kokotin, G V Kolmakov, N F Lazareva, E V Lebedeva, A A Levchenko, O I Levchenko, M K Makova, Yu M Romanov, and V B Shikin (all staff members of the Institute of Solid State Physics, RAS), actively worked to make the workshop a success.

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Quantum states of neutrons in a gravitational field and the interaction of neutrons with nanoparticles

V V Nesvizhevskiĭ ¶

1. Introduction

This report presents the results of ultracold neutron (UCN) studies we have conducted over the past few years at the high-flux research reactor of the European Centre for Neutron Research at the Laue–Langevin Institute in Grenoble, France. ILL, the institution currently dominating international studies in fundamental neutron physics, has Russia among its member countries. Since the first UCN storage experiment [1] in Dubna in 1968, there have been much research and applied activity in this dynamic field.

The great interest in UCNs arises from the fact that slow enough neutrons are reflected totally from a surface — a unique property which makes it possible to confine UCNs in a closed container for a period of time comparable to their beta-decay lifetime, which is ~ 15 min. The probability for a UCN to be lost into the walls can be much lower than that for their beta decay. This long confinement time allows high-precision or very sensitive measurements both of neutron properties and of their interactions with matter and fields.

¶ The author is also known by the name V V Nesvizhevsky. The name used here is a transliteration under the BSI/ANSI scheme adopted by this journal.