# PREFACE

We would like to introduce the report on the scientific activity of the Frank Laboratory of Neutron Physics for 2002. The first part is a brief review of the experimental and theoretical results of investigations achieved in the main scientific directions – condensed matter physics, neutron nuclear physics and applied research. The second part includes reports on the status of the IBR-2 pulsed reactor and IREN project. The third part is devoted to the IBR-2 spectrometers complex and computing infrastructure. The fourth part presents the investigations that characterize the main directions of research in greater detail. The report completes with the list of publications for 2002.

In 2002 the IBR-2 reactor operated, as planned, 8 cycles in strict accordance with the approved working schedule. It should be noted, however, that the deficit financing and delays in funding the IBR-2 modernization project and the IREN project resulted in the suspension of works on the modernization project and in a considerable delay in the realization of the IREN project.

In the course of the year a significant modernization of the SPN and YuMO spectrometers at the IBR-2 reactor was carried out and since the autumn cycle they operate for users.

High Energy Neutron Detector (HEND) designed and created by the Russian Space Research Institute under the contract between the Russian Space Agency and NASA in collaboration with FLNP successfully started regular operation on the Martian orbit. Together with other detectors carried by the Mars Odyssey 2001 spacecraft, HEND provides the decisive evidence that the surface layers of Mars contain huge amount of water.

The Frank Laboratory of Neutron Physics continues to be one of the leading neutron centers of Europe and develops in spite of all the difficulties connected with severely limited funding.

***A.V. Belushkin***

***Director***

*15 March 2003*

# 1. SCIENTIFIC RESEARCH

## 1.1. CONDENSED MATTER PHYSICS

**Organization of research work and instrument development**. In 2002 under theme 1031, neutron scattering investigations in condensed matter physics were mainly conducted at the IBR-2 reactor. In addition, physicists of the FLNP Scientific Department of neutron investigations of condensed matter working within the framework of theme 1031 carried out a number of experiments in neutron laboratories of Europe by the accepted proposals. During the reported year IBR-2 operated for eight working sessions. The beam time for experiments at the reactor spectrometers was distributed in accordance with the recommendations of experts on the submitted proposals and existing long-term agreements.

In 2002, scientific investigations were carried out on 10 spectrometers: HRFD, DN-2, DN-12, SKAT, YuMO, EPSILON, REFLEX-P, KDSOG, NERA, and DIN. A large volume of methodical works was performed on the spectrometers FSD, SPN, EPSILON, and REFLEX-P. On the neutron Fourier diffractometer FSD intended to study internal stresses in materials and engineering products, work on the detector system continued. In particular, in October two new elements of ±90°-detectors based on ZnS(Ag)-scintillators of modernized configuration with an increased solid angle, were installed. During the year on SPN a radical modernization was carried out as a result of which the installation of a new head part of the spectrometer was completed, the multichannel neutron polarizer intended for small-angle investigations was put into operation (its polarization efficiency exceeded 90% in a wide interval of wavelengths), and the multichannel efficient focal analyzer of polarization was commissioned. On EPSILON, nine new detectors with collimators were installed, thus, the number of detectors was increased to 36. On REFLEX-P, the neutron-optical system was assembled anew, resulting in a 4-times enhancement of polarized beam intensity. In addition, methodical work on the improvement of parameters, experimental conditions and primary data processing continued on all the IBR-2 spectrometers.

**Scientific results. Diffraction.** In 2002, as the investigations of the $(La_{1-y}Pr_y)_{0.7}Ca_{0.3}MnO_3$ (LPCM-*y*) compound continued, a series of neutron diffraction experiments (with HRFD, DN-12 and DMC on SINQ source) to obtain information on the magnetic phase diagram of the compounds with the predominance of $^{18}O$ isotope (up to 75%) were carried out. Their main result is that the phase diagrams of LPCM-*y*/$^{16}O$ and LPCM-*y*/$^{18}O$ are qualitatively identical (**Fig.1**). This gives grounds to believe that the giant isotope effect in electroresistance, observed earlier for the LPCM compound with $y$=0.75, is a manifestation of a transition to another phase state (for more details see Experimental Reports).

The crystal and magnetic structures of the new layered complex manganese oxide $Sr_2MnGaO_{5+x}$ with an intermediate content of oxygen x=0.13 and 0.41 (between the limiting values x=0 and 0.5) were investigated. As was demonstrated earlier in the limiting cases the magnetic structures differ significantly and correspond to antiferromagnetic (AFM) *G*- and *C*-types for x=0 and 0.5, respectively. It turned out that while the composition with x=0.13, as the temperature decreases ($T_N$≈200 K), undergoes a transition to a homogeneous antiferromagnetic state of *G*-type (i.e. its behavior is the same as of the composition with x=0), in the composition with x=0.41 magnetic phases of both *G*- ($T_N$≈140 K) and *C*- ($T_N$≈110 K) types with approximately equal concentrations appear (**Fig.2**). The unusual fact is the lack of evidence of any structural differences in the two arising magnetic phases.

On the DN-12 spectrometer, a lot of experiments to study the behavior of both the atomic and magnetic structures of crystals at high pressures were conducted. For example, the crystal structure of mercury chalcogenides $HgSe_{0.7}S_{0.3}$ and $HgTe_{0.85}S_{0.15}$ in the pressure range up to 8 GPa was investigated. On the basis of the obtained structural data the phenomenological model of a structural phase transition from a cubic blende structure to hexagonal cinnabar structure occurring in these compounds, was suggested.

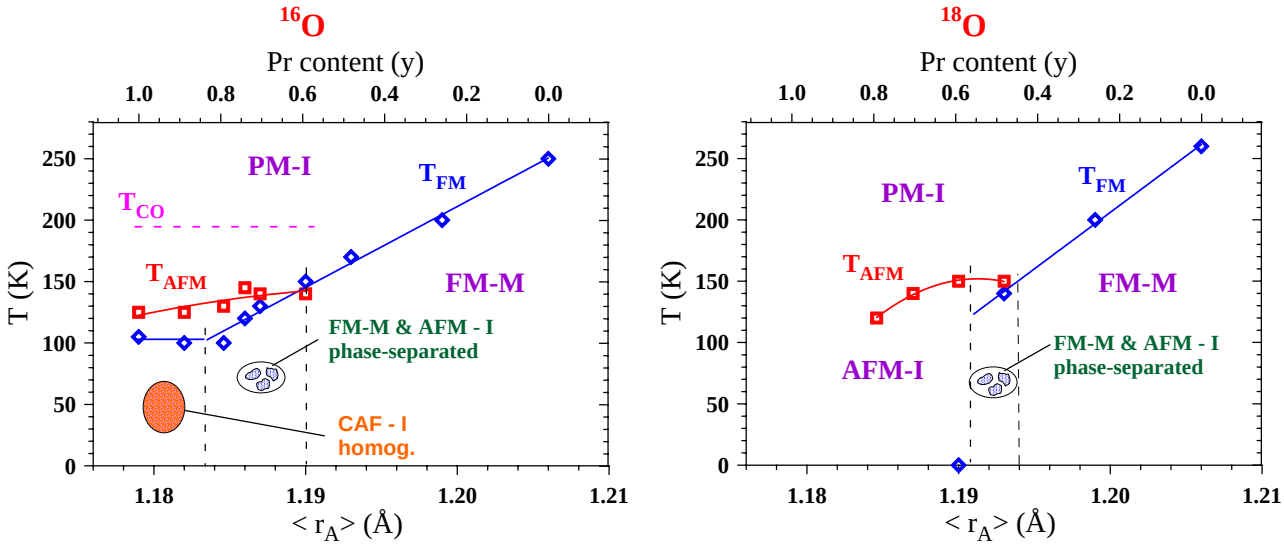


***Fig.1.*** *Magnetic phase diagrams for the* $(La_{1-y}Pr_y)_{0.7}Ca_{0.3}MnO_3$ *compositions containing oxygen isotopes* $^{16}O$ *(left) and* $^{18}O$ *(right).*

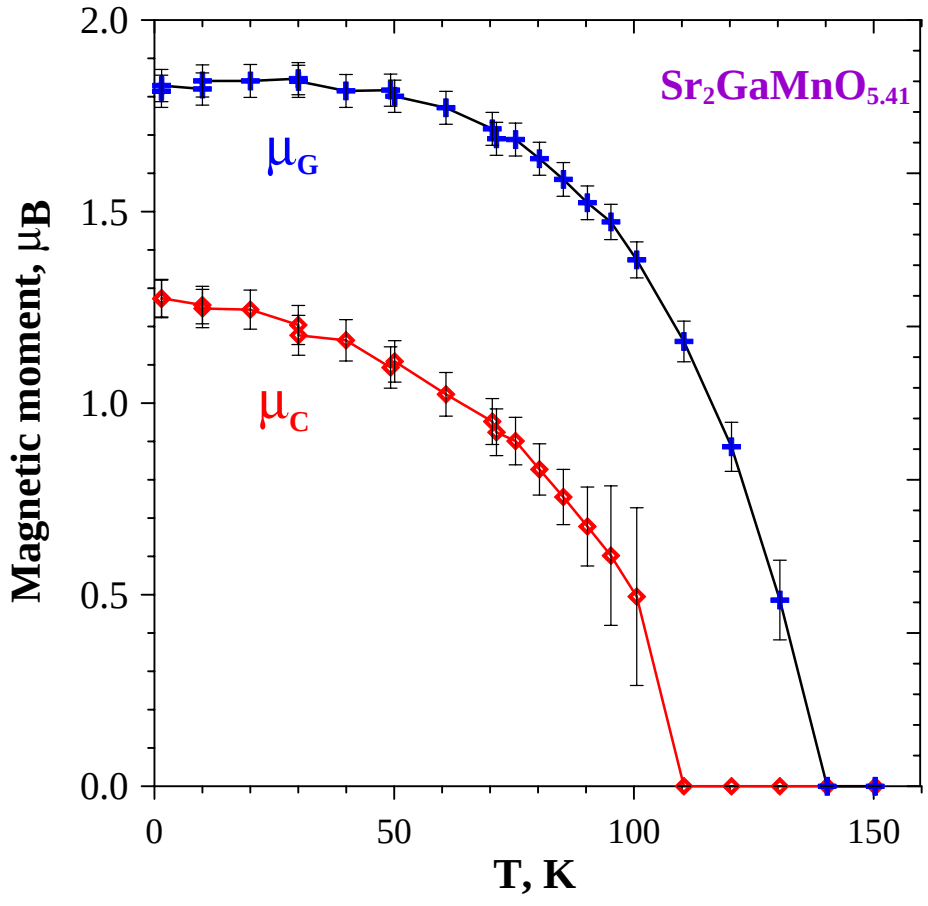


***Fig 2****. Dependence of the value of magnetic moments in* $Sr_2MnGaO_{5.41}$ *on temperature. At* $T \approx 140$ *and 110 K there occur two sequential magnetic phase transitions with the formation of the G- and C-type antiferromagnetic phases, i. e. magnetic phase separation develops.*

The crystal and magnetic structures of manganites $Pr_{0.7}Ca_{0.3}Mn_{1-y}Fe_yO_3$ ($y$=0, 0.1) and $Pr_{0.8}Na_{0.2}MnO_3$ with the CMR effect were investigated at pressures up to 4.5 GPa and in the temperature interval from 16 to 300 K with the DN-12 spectrometer. For the first time it was found that in these compounds, which have significantly different magnetic structures at a normal pressure

($Pr_{0.7}Ca_{0.3}MnO_3$ and $Pr_{0.8}Na_{0.2}MnO_3$ have the AFM structure of pseudo-*CE* type, while $Pr_{0.7}Ca_{0.3}Mn_{0.9}Fe_{0.1}O_3$ is ferromagnetic), stabilization of the AFM state of type *A* with characteristic propagation vector **q**=(010) takes place at high pressures and low temperatures (for more details see Experimental Reports).

The effect of quasihydrostatic pressure up to 4 GPa and hydrostatic pressure up to 2.5 GPa on $Fe_2O_3$ was studied. It was revealed that in quasihydrostatic conditions even at pressure P~2 GPa a spin-reorientation phase transition occurs, resulting in a change of the angle of Fe magnetic moments in respect to rhombohedral axis (111) of the crystal. At the same time, in hydrostatic conditions up to pressure 2.5 GPa the reorientation of magnetic moments was not observed.

On DN-2, $Pb_{0.8}Sn_{0.2}Te$ monocrystals in which anomalies in temperature dependence of some macroscopic properties had been earlier detected, were studied. The diffraction experiments verified the hypothesis about multiple phase transformations in this compound. The situation in $Pb_{0.8}Sn_{0.2}Te$ appears to be analogous to that observed in the narrow-gap semiconductor InSe for which the analysis of kinetic, galvanomagnetic and thermoelectric phenomena testifies the existence of structural Peierls phase transitions. Moreover, the temperature dependence of specific resistance investigated for InSe suggests the instability of structure and presence of some phase transformations. To clear up the situation it is proposed to carry out structural investigations of InSe on mono-and polycrystalline samples.

**Small-angle neutron scattering.** Within the framework of studies of cluster state of fullerenes in solutions the experiments on small-angle neutron scattering from the solution of $C_{60}$ in carbon disulfide ($C_{60}/CS_2$) and the colloidal solution of $C_{60}$ in water ($C_{60}$FWS) were performed. For the system $C_{60}/CS_2$ it was shown that the formation of small clusters with the mean aggregation number of about four takes place in solution. The aggregation number does not depend on the temperature ($15 \div 30^oC$) and concentration ($4 \div 8$ mg/ml). These results cast doubt on the use of the drop model to describe the cluster structure in solution. In the case of $C_{60}$FWS large polydispersity over a wide range of sizes up to 50 nm was revealed. The contrast variation based on different mixtures of light and heavy water points to the presence of a component in the aggregates, which is different from fullerenes. This component is assumed to be responsible for stabilization of the dispersions. A number of hypotheses about its origin, in particular, the formation of a specific hydration shell around fullerenes, are being discussed (for more details see Experimental Reports).

The conformation of the elongation factor eFF1A from mammal cells (rabbit) in solutions was investigated by means of small-angle neutron scattering and scanning microcalorimetry. It was found that in contrast to a bacterial analogue the protein has no fixed structure in solution. This follows from the fact that the radius of gyration, 5.2 nm, determined from the small-angle scattering curves is considerably greater than that of the prokaryotic eEF1A, while the specific heat of denaturation of the studied eEF1A, 4 cal/g, obtained by the scanning microcalorimetry is significantly lower than 7 cal/g for the prokaryotic eEF1A calculated for the same denaturation temperature. The small-angle neutron scattering data suggest that the studied eEF1A becomes more compact when forming a complex with the diacyl-tRNA.

**Polarized neutrons and neutron optics**. The reflectometry was applied to study the interface formation during the synthesis of multilayers from the P(dS-b-nBMA) copolymers composed of blocks with different molecular weight. It was found that the numerous peculiarities observed in the off-specular neutron scattering spectra are connected with the presence of islands or pores randomly distributed on the film surfaces, as well as with the formation of complex interphase boundaries.

Within the framework of investigations of multilayer magnetic structures the reflectometry experiments on the MgO (001) / $[Fe(x\ ML) / V(y\ ML)]_N$ / Pd structures were carried out. The magnetization profile and distribution of Fe and V atoms at interfaces were obtained. Nuclear and magnetic potentials drop faster and grow more rapidly upon passing the interface in a direction

from vanadium to Fe than in a direction from Fe to vanadium. This fact is determined by the asymmetry in the interpenetration of Fe and vanadium atoms.

On the REFLEX-P spectrometer, the high-precision experiment to search for the surface magnetic excitations in magnetic thin film structures was continued. A full set of experimental data has been collected, and at the present time the creation of a mathematical model to treat the obtained results is in progress.

**Inelastic neutron scattering.** On the NERA spectrometer, the structural phase transitions and dynamics of solid mesitylene, as well as the influence of concentration and temperature on the dynamics of ammonium groups and phase transitions in mixed crystals $Rb_{1-x}(NH_4)_xBr$, were investigated. Mesitylene known as an organic solvent with a comparatively low freezing point of 227 K holds much promise for cold neutron sources. The results of simultaneous measurements of both the diffraction and inelastic neutron scattering demonstrated that the phase composition of solid mesitylene depends on the cooling rate, i.e. mesitylene is an interesting example of a relatively simple molecular crystal which exists at low temperatures in various structural modifications with significantly different dynamic characteristics (**Fig.3**). In the future this will make it possible to study the packing effect on the lattice dynamics and rotation dynamics of methyl groups (for more details see Experimental Reports).

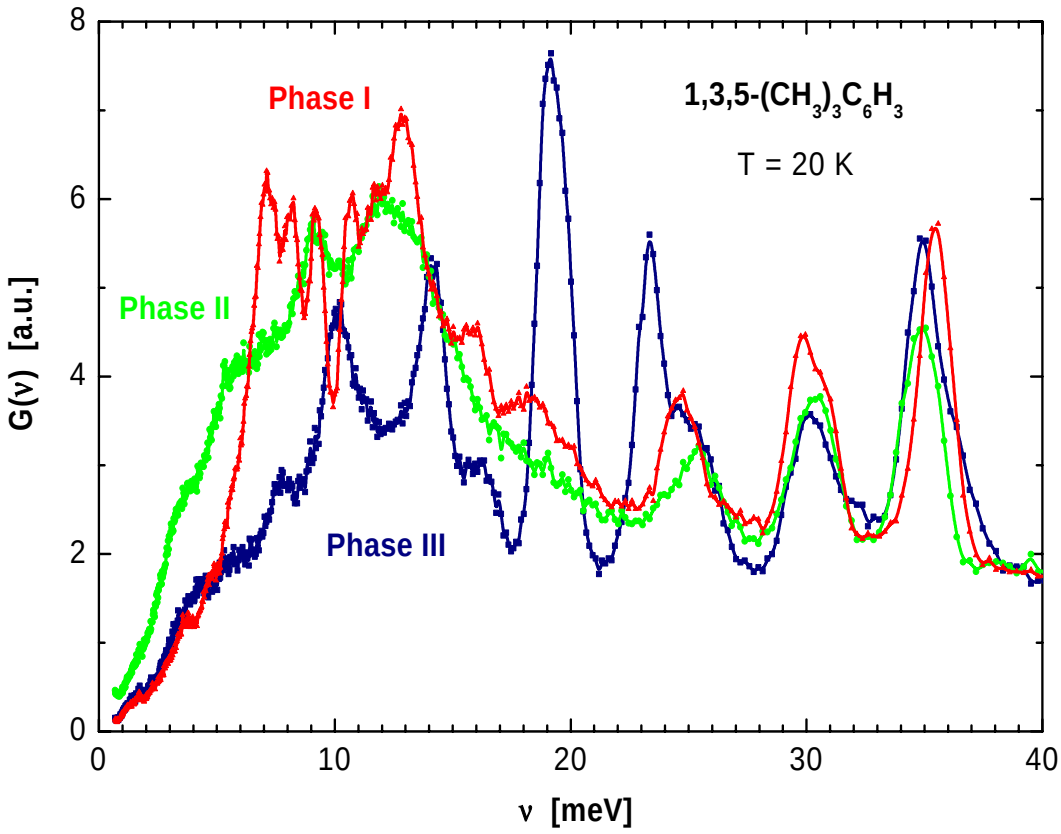


***Fig.3.*** *Phonon state density in different structural phases of mesitylene.*

The investigations of the crystalline electric field (CEF) effects in $RAgSb_2$, where R=Ce, Tm, Er and Ho, were carried out by means of inelastic neutron scattering. The CEF parameters, as well as the level schemes and wave functions were determined. The temperature dependence of magnetic susceptibility calculated for different crystallographic directions using the CEF parameters agrees well with the experimental results for monocrystals. The analysis shows that magnetocrystalline anisotropy in these compounds is determined mainly by CEF.

**Applied research.** The diffraction study of textures of amphibolites and gneisses from the section of the super deep borehole SG-3 in Kola Peninsula and their analogues from the surface, continued. The modelling of the elastic wave speed distribution in the studied samples was conducted using the quantitative information on the texture and data on elastic modules of rock-forming minerals. The analysis of the obtained data will allow us to find out the contribution of the oriented mineral components into the total elastic anisotropy of rocks. This is necessary to establish regularities between texture peculiarities and deformation mechanisms, as well as metamorphic processes responsible for the texture formation in the process of evolution of lithosphere.

Complex application of neutronographic texture analysis and ultrasonic spatial sounding of spherical samples at various high pressures made it possible to provide a physical explanation to different character of change in anisotropy of mantle olivinite properties and to establish the fact of reduction in anisotropy factor with an increase in pressure for olivine xenolites.

Shock deformation of samples consisting of sandstone and olivine was investigated. For this purpose strain values for untextured multiphase sandstone, containing quartz, various kinds of feldspar and mica were measured. The sample was shock deformed to model conditions of strong impact. The deformation was scanned across the interface between dunite (olivine) and quartzite (quartz). The data obtained with the help of time of flight neutron diffraction were analyzed together with the results of research performed using X-ray synchrotron radiation and microstructural measurements. The results show that residual strains differ widely depending on a characteristic combination of texture, peculiarities of applied deformation and microstructural features of rocks. The grain size of scattering crystals was estimated by analyzing peak profiles (synchrotron radiation diffraction) on each side of the phase interface.

To explain the swelling mechanism in graphite blocks irradiated by neutron fluxes, a number of in-situ experiments to study changes in anisotropy in the samples of reactor graphite under the action of compression stresses, were carried out. Investigations were performed both in elastic and plastic deformation regions. It was found that the graphite crystal lattice remains unchanged until stresses are close to the breaking stress value. It is possible that this unusual result can be connected with the initial porosity of the samples, i.e. the action of compression stresses reduces to the collapse of pores without significant elastic deformation of the crystal lattice. The obtained data will be verified on the graphite samples cut out from different places and variously arranged locations in the reactor block.

On the DN-2 diffractometer, the ordering phenomenon in NiCr alloy, which is a constructional material, was studied. A number of NiCr-based compounds doped with Mo, Si and S were investigated. Plates annealed at temperatures of 300, 350, 400 and 450°C were used as samples. Only in one (alloy 32XHM annealed at T=450°C) of 32 studied samples superstructure diffraction peaks indicative of the ordering of Ni and Cr atoms were detected. It was found that in this sample the superstructure $Ni_2Cr$ is formed. Upon ordering, chrome and nickel atoms are arranged on planes (110) of initial cubic cells (space group Fm3m, $a$=3.62 Å) so that one layer of chrome is followed by two layers of nickel. The unit cell of this lattice is orthorhombic (Pnnm) with $a$ =7.653 (1), $b$ =2.560 (1) and $c$ = 3.631 (1) Å. The ordering proceeds in the whole bulk of the sample.

# 1. SCIENTIFIC RESEARCH

## 1.2. NUCLEAR PHYSICS WITH NEUTRONS

### Introduction

In the year 2002 the program for experimental research in neutron nuclear physics in the Frank Laboratory of Neutron Physics (FLNP) included the following FLNP-traditional research directions: studies of spatial and time parity violation at interaction of neutrons with nuclei, of quantum mechanical properties and the dynamics of the fission process, experimental and theoretical investigations of electromagnetic properties of the neutron and neutron beta-decay, gamma-spectroscopy of neutron-nucleus interactions, obtaining of new data for the purposes of reactor technology and nuclear astrophysics, and applied research.

The shut down of the IBR-30 reactor has shifted the focus of the experimental investigation to the IBR-2 and EG-5 machines in FLNP as well as to basic facilities in other nuclear centers in Russia, Bulgaria, Poland, Czech Republic, Germany, Republic of Korea, France, USA and Japan.

### 1. Experimental investigations

#### *1.1. Spatial and time parity violation at interaction of neutrons with nuclei*

##### 1.1.1 Search and investigation of the structure of sub-threshold p-resonances of lead isotopes by combined correlation gamma-spectroscopy

To search for a sub-barrier neutron p-resonance of lead isotopes and to explain the parity violation effect **(**spin rotation of the neutron polarized perpendicularly to the momentum on going through a lead target), experiments were conducted on channel 1 of the IBR-2 reactor. The energy dependence of the neutron radiative capture cross section was studied. The expected deviation of the dependence from the law $1/\sqrt{E}$ due to the existence of such a resonance is shown in **Fig. 1.**

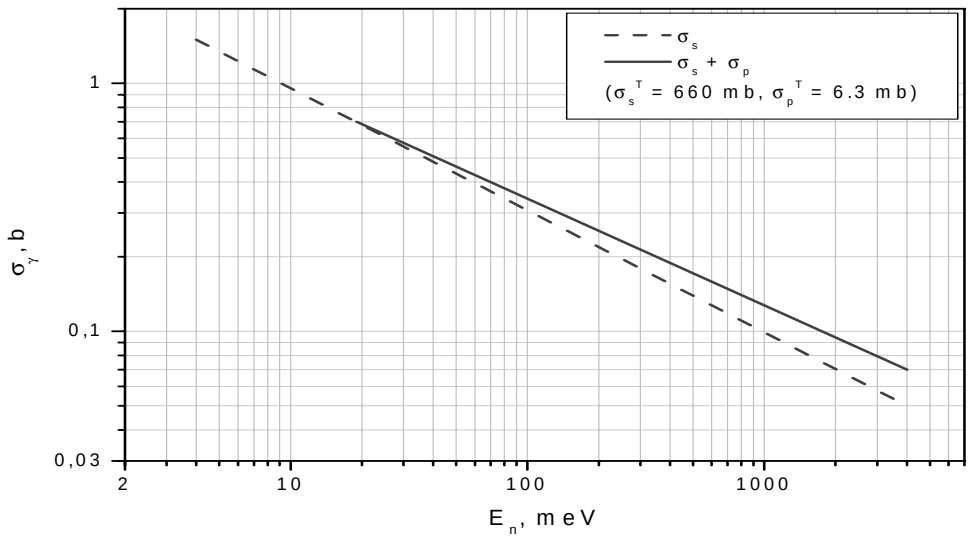


***Fig. 1.*** *The energy dependence of the neutron radiative capture cross section for s- and s+p waves.*

At neutron energies from 80 meV to 3 eV there were measured the radiative capture gamma-spectra of a 4.7 g sample of lead enriched with a $^{204}$Pb isotope on the spectrometer COCOS whose schematic is shown in **Fig. 2.**

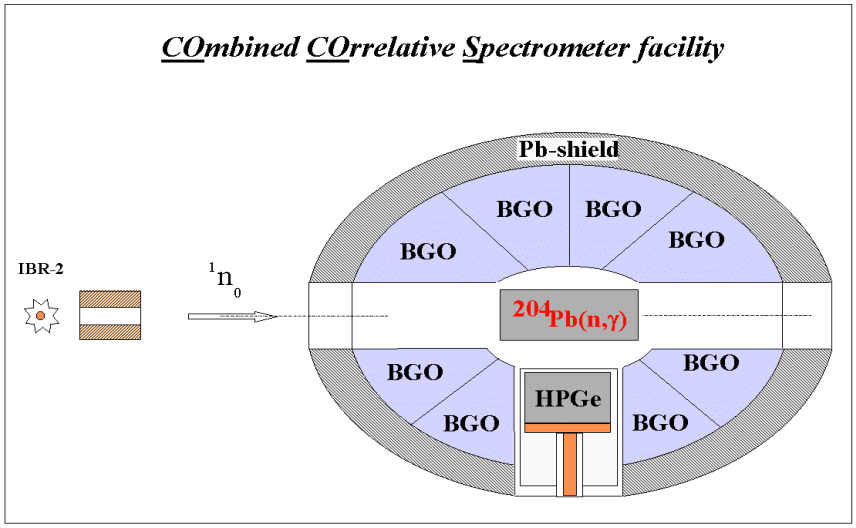


***Fig. 2.*** *The schematic of the gamma-spectrometer COCOS.*

The fundamental possibility of the precision gamma-spectroscopy of small quantities of lead isotopes in unfavorable background conditions of a pulsed neutron source and the effectiveness of the chosen methodological approach were demonstrated. The preliminary results show no demonstration of the sought resonance of the isotope $^{204}$Pb within a 15%-accuracy.

**1.1.2 The measurement of the P-odd asymmetry of triton emission in the reaction $^6$Li(n,α)$^3$H and recent results of the measurement of the P-odd asymmetry of γ-quanta emission in the reaction $^{10}$B(n,α)$^7$Li*→γ→$^7$Li(o.c.)**

Experiments to measure P-odd asymmetry of the type $\alpha_{PNC}(\mathbf{s_n},\mathbf{p_t})$ in the reaction $^6$Li(n,α)$^3$H were performed on cold (<$\lambda_n$>=4.7 Å) polarized (94%) neutron beams of the reactor PF1B in ILL, Grenoble, France by a FLNP JINR-PINP-ILL collaboration. The details of the experiment are described in an article included in the special section of the present report. During the main measurements for 18 days $\alpha^t_{PNC}$ = -(8.1 ± 3.9)·10$^{-8}$ was obtained. In addition, measurements to estimate the contribution of the P-even left-right asymmetry $\alpha_{LR} \le 8\cdot10^{-9}$ were carried out. Our results and those of similar measurements made in PINP, Gatchina, helped estimate the value of the weak meson constant corresponding to the neutral current - $f_\pi \le 1.2\cdot10^{-7}$. The measurements will be continued.

The first experiment to measure the P-odd asymmetry of γ-quanta emission in the reaction $^{10}$B(n,α)$^7$Li*→γ→$^7$Li(o.c.) was made in 2001 in Grenoble using the polarized neutron beam of the reactor PF1B of ILL. The main measurement yielded the value of the P-odd asymmetry of the type $\alpha_{PNC}(\mathbf{s_n},\mathbf{p_\gamma})$ - $\alpha$ = + (8.8±4.6)·10$^{-8}$ and a zero experiment revealed a considerable background effect, $\alpha_0$ = -(14.8±3.3)·10$^{-8}$. In the 2002-year's experiment much attention was paid to the clarification of the nature of the background effect. Investigations to estimate possible contribution to the measured value from reactions with the construction materials of the facility and samples, such as lead, aluminum, lithium, and air, were carried out. It was established that the sample used in the first experiment for a zero test was locally contaminated, most likely, with chlorine (or bromine) and this largely affected the background. The basic results of the experiment (preliminary): measurements with a sample - $^{10}$B - $\alpha$ = -(11.0 ± 6.6)·10$^{-8}$, 0-test - $\alpha_0$ = (0.7 ± 3.7)·10$^{-8}$. The calculation of the investigated reaction in the framework of the cluster model using the "best" values of the weak meson constant gives $\alpha^{theor}$ = -7.24·10$^{-8}$ for P-odd correlation. The achieved experimental precision does not allow the estimation of the weak meson constant $f_\pi$ yet. The measurements will be

continued using the new supermirror polarizer that provides a many times higher intensity of polarized neutrons.

### 1.1.3 Parity violation in compound nuclei: TRIPLE's latest results

Under the collaboration Time Reversal Invariance and Parity at Low Energy (TRIPLE), analysis of measurements of parity-violating spin rotation in the region of the 0.75 eV neutron p-wave resonance of $^{139}$La completed. The experiment was done at the Los Alamos pulsed source by measuring neutron transmission with two optically polarized $^{3}$He cells used as a polarizer and analyzer of neutron spin. Analysis of the data yields the weak matrix element $xW=(1.71\pm0.25)$ meV in agreement with the earlier experimental data on lanthanum.

### 1.1.4 Current status of the KaTRIn project

Under the **KaTRIn** project for the preparation of the experiment to test time invariance in nuclear reactions, a program for the modeling of polarized epithermal neutron transmission through polarized targets has been developed. The program works with cross section libraries analogous to those incorporated in MCNP. Additional libraries to take into account spatial and time parity violation effects are calculated in the two-level approximation.

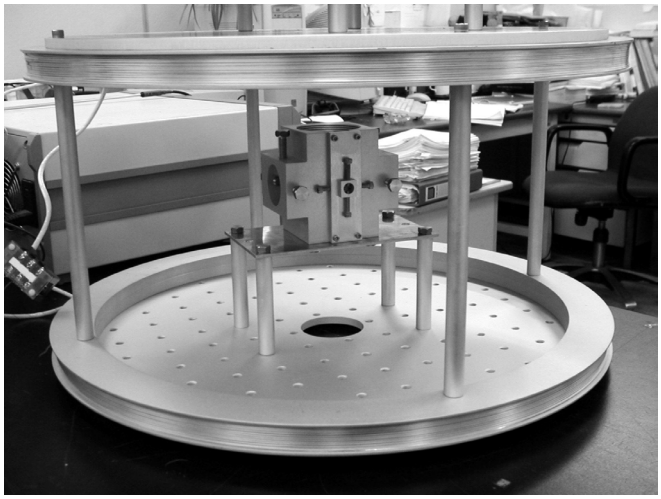

***Fig. 3.*** *The system of Helmholtz rings assembled with a target heater.*

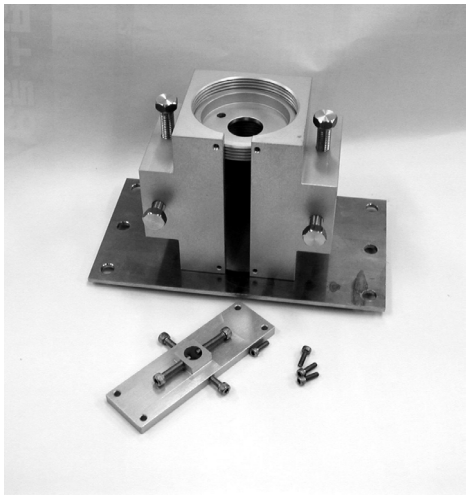

***Fig. 4.*** *The target heater.*

Under a FLNP JINR – FIAN (Physical Institute of Academy of Sciences) collaboration aimed at improving the neutron polarizer on the basis of $^{3}$He with optical pumping, the system for the filling of cuvettes with $^{3}$He and rubidium using high purification filters of $^{3}$He (getter) is being modernized.

In parallel, work to create a neutron polarizer on the basis of a $^{3}$He gas target with laser pumping for PAL and the reactor «HANARO» (KAERI) is carried out. A system of 50 cm diameter Helmholtz rings with a power supply, a heater for the target, and the fastening elements are manufactured. The photographs of the rings and heater assembly are presented in **Fig. 3**. **Figure 4** shows the heater in the knock-down form. The measured magnetic field in the center is 23 Gauss, which is in full agreement with the calculation.

In the future, the system will be used in joint FLNP JINR – PAL – KEK experiments of testing time invariance in nuclear reactions.

### 1.1.5 Development of an aligned nuclear target for the search of T-invariance

To investigate T-noninvariance effects in the neutron-nuclei interaction by P-even T-odd five-fold correlation **c**[**pI**](**pI**) (where **c**, **p** and **I** are the neutron spin, neutron moment and the nucleus spin), it is necessary to have a sample with aligned nuclei. To align quadrupole nuclei in monocrystals, a dynamic method involving the saturation of NCR-transitions using a SHF electromagnetic field was suggested. In this connection, studies of the applicability of the nuclei dynamic alignment method (NDA) for the investigation of T-noninvariance effects were carried out in 2002:

- In cooperation with IONKh the NCR method was used to perform investigations with a monocrystal of lutetium niobate with a paramagnetic admixture of trivalent chromium. Three resonance lines corresponding to transitions between levels with the spins 7/2, 5/2, 3/2 and 1/2 are found. The transition frequencies differ slightly from those obtained previously with a ceramic sample.
- The relative position of the electric field gradient direction and the main C-axis of the crystal is determined.

## *1.2 Neutron-induced and spontaneous fission*

### 1.2.1 Interference effects in the resonance-neutron induced fission of $^{239}$Pu

In the framework of the new Barabanov-Furman theoretical approach to the description of fission, which employs the spiral representation of output fission channels and a conventional theory of nuclear reactions, there were obtained formulas for the partial and differential cross sections of fission. Making use of them, of the multilevel $R-$matrix formalism and of the minimization program FUMILI there was developed a program for analysis of the experimental

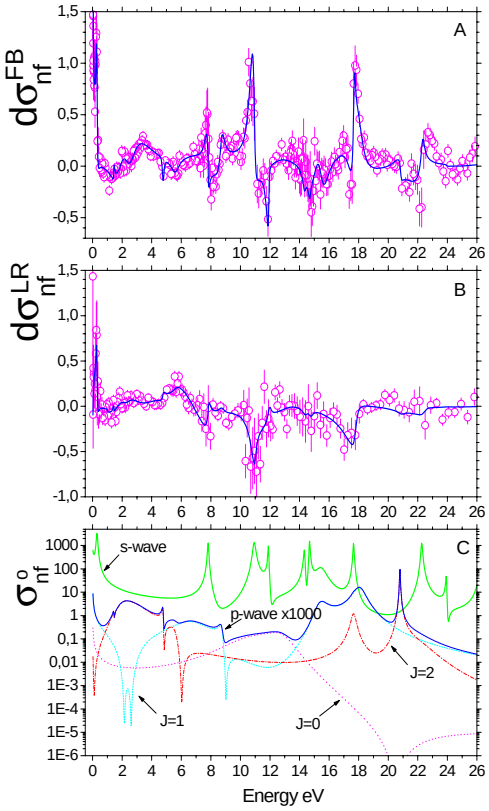


***Fig. 5.*** *The results of fitting of the P-odd data on the angular asymmetry "forward-backward" (A) and "left-right" (B) of fission fragments from the reaction* $^{239}Pu(n,f)$ *in the region* $0.02-25\,eV$, *points – experiment, curves – fitting results. C – s- and p-wave cross sections (bearing indication of spin components for p-wave fission cross section). The fitting was done taking into account the resolution of the spectrometer.*

data with respect to angular anisotropy of the resonance neutron-induced fission of aligned nuclei and with respect to P-odd angular correlations “forward-backward” and “left-right” due to the interference of s- and p-wave resonances. The created program made it possible to do analysis of the experimental data on P-even angular correlations obtained for $^{239}Pu$ at the booster IBR-30+LUE-40. Earlier, analysis of such data was performed using a less strict approach suggested by Sushkov-Flambaum in 1982. The advantage of the new method and the new program is the possibility of joint analysis of the entire data set on total, partial and differential cross sections using a single set of resonance parameters. **Figure 5** illustrates the results of fitting of the experimental data on the angular correlations “forward-backward” and “left-right” for $^{239}Pu$. Calculations have shown that the description of the experimental data with a satisfactory value of $\chi^2$ is achieved for the different sets of p-resonances (in their number and spins) due to a low statistical accuracy of the experimental data, limited energy resolution and a large number of the introduced parameters of p-wave resonances. Therefore, the continuation of the experiments in the conditions of good statistics and resolution is of much interest.

### 1.2.2 Interference effects in the angular distribution of fission fragments

In the conducted cycle of investigations of the angular anisotropy of fission fragments from the resonance neutron-induced fission of $^{235}U$ (Phys. of Atom. Nucl., **62,** p.840 (1999)) there remained unsolved the problem of reliable normalization of the angular anisotropy coefficient $A_2(E)$ extracted from the experiment. Its absolute normalization depends on the correct assessment of the alignment of $^{235}U$ spins in the target, which is a monocrystal of uranyl-rubidium nitrate, which, in turn, depends on the precision of the superfine coupling constant $P/k$ of the monocrystal. Measurements of the temperature dependence of the angular anisotropy of alpha particles in $^{233}U$ (basic activity of the sample) to refine the constant $P/k$ for the investigated nucleus were undertaken. Cooling the sample to $0.2K$, an accuracy of 30 % was obtained. To achieve the goal set (an accuracy of $5-10\,\%$) it is necessary to continue the experiments at temperatures down to several $mK$.

### 1.2.3 Experiments to investigate triple fission

In cooperation with GSI and the Technical University (Darmstadt, Germany) an experiment to study the spontaneous fission of $^{252}$Cf accompanied with emission of light charged particles was performed. In the experiment, a double ionization chamber allowing the registration of the energy and direction of two fission fragments with a high efficiency was used. To register light charged particles, a set of ΔE-E telescopes fixed at nearly 90° angles to the chamber axis was used. In addition, γ-quanta from the fission were registered with two large-volume segmented germanium detectors (GSI Super Clover detectors). The total angular resolution of the detecting systems makes it possible to obtain a resolution in gamma-quanta of ΔE / E =1% (after correcting for the Doppler effect), which allows speaking about the precision gamma-spectroscopy of moving fragments. Besides, of interest is the possibility of observation of gamma-emission from the excited states of triple particles. The probability of light charged particle formation is a very important parameter for the theory of triple fission as it may allow the assessment of the temperature of the nucleus at the moment of fission.

### *1.3 Gamma-spectroscopy of neutron-nucleus interactions*

#### 1.3.1 Investigation of two-step gamma-cascades

Processing and analysis of the to-date accumulated experimental data on two-step cascades in nuclei earlier not studied continue. Analysis of such data for the nuclei $^{60}$Co and $^{184}$W completed.

The scheme of excited levels of the isotope $^{184}$W belongs to the class of those studied well in various nuclear reactions. Nevertheless, the information about 240 energy-resolved cascades allows one to extend the energy range of excited levels whose decay modes are determined over two times. Such information is necessary for the testing of today's models of the nucleus.

For the compound nuclei $^{185,187}$W and $^{191,193}$Os the intervals of the most probable densities of levels excited by primary dipole transitions on thermal neutron capture and their radiative strength functions are determined from the intensity of two-step cascades. For the tungsten isotopes the discussed parameters of the cascade gamma-decay of the neutron resonance are obtained with a less statistical and systematic error than the earlier results.

In all the nuclei a clearly expressed step-like structure is observed in the excitation energy in the interval from ~1 to ~2-2.5 MeV. In the framework of a generalized model of the superfluid nucleus this fact is evidence of the existence of appreciable influence of the coupling nucleon interaction on the observed properties of the nucleus at least below half neutron binding energy.

#### 1.3.2 Spectroscopy of the nucleus $^{159}$Gd

The nucleus $^{159}$Gd lies in the middle of the rare-earth region, is strongly deformed and can be represented as an even-even ellipsoid with a neutron on the outermost shell. The low-lying levels group into rotational bands built on single quasiparticle states. The basic properties of such a system can be looked at as interaction of a single particle with the field of the nucleus $^{158}$Gd whose properties are well known. The levels of $^{159}$Gd were studied in the reaction $^{158}$Gd(n,gamma) in FLNP JINR, in BNL (Brookhaven, USA) and in ILL (Grenoble) as well as in the transfer reactions $^{158}$Gd(d,p) and $^{160}$Gd(d,t) at the Van de Graaff accelerator in the Technical University (Munich). In 2002, the results of measurements of the transfer reactions $^{158}$Gd(d,p) and $^{160}$Gd(d,t) were analyzed. The charged particles from the reaction were separated in energy and type in the Q3D spectrograph shown schematically in **Fig. 6** and were registered with a position-sensitive detector.

The proton yield from the reaction $^{158}$Gd(d,p) was measured at 10 angles. To describe theoretically the angular distributions of protons energy-related with definite final states of $^{159}$Gd, the DWBA approximation was used. The reaction $^{160}$Gd(d,t) was measured at an angle of 8, 40, 45 or 50 degrees with unpolarized deuterons and at an angle of 12, 16, 20, 25, 30 or 35 degrees with polarized deuterons. For a theoretical description of angular distributions there was also used the

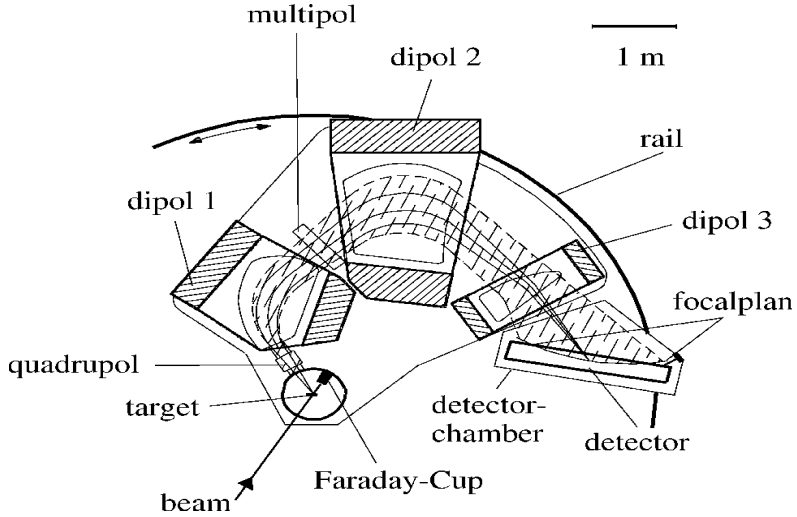


***Fig. 5**. The Q3D spectrograph at the Van de Graaff accelerator in the Technical University (Munich).*

DWBA approximation. An analysis of the results has made it possible to determine the spin and parity of levels in $^{159}$Gd up to the excitation energy 2320keV. Basing on the results of measurements of all of the reactions rotational bands in the nucleus $^{159}$Gd to the energy 1220 keV were built.

#### 1.3.3 Investigation of level densities and radiative strength functions of Mo and Si isotopes

Work to investigate nuclear level densities and radiative strength functions continued in collaboration with the University of Oslo (Norway) and the Livermore National Laboratory (USA). A joint experiment was carried out at the cyclotron of the University of Oslo to study the nuclei $^{96}$Mo and $^{97}$Mo using the reactions ($^{3}$He,$\alpha\gamma$) and ($^{3}$He,$^{3}$He$\gamma$). Collaborative processing of the results of the previous measurements of the nuclei $^{27}$Si and $^{28}$Si completed. For the nuclei, the level densities in the excitation energy interval down to the neutron binding energy as well as the energy dependence of radiative strength functions were obtained. Methodological work to demonstrate a method of the experimental investigation of the electromagnetic nature of the pigmy resonance in the radiative strength function by combined analysis of the data from the reactions ($^{3}$He,$\alpha\gamma$) and (n,2$\gamma$) in application to the same investigated nuclei was carried out. Processing of the results of the joint experiment to study the thermal neutron-induced reaction $^{171}$Yb(n,2$\gamma$)$^{172}$Yb, which was conducted in the Los Alamos National Laboratory at the end of 2001, continued.

#### 1.3.4 Measurement of gamma-spectra for separate resonances of tantalum

In cooperation with the University of Lodz (Poland) experiments aimed at finishing of the measuring technique of gamma-spectra for separate resonances of tantalum were performed. An original idea to use a very thick sample, which would suppress the background due to the spectrometer itself within the limits of the investigated resonance, has made it possible to reduce the background due to gamma-quanta from neutron capture in the Germanium detector by an order of magnitude and for the first time to measure gamma-spectra of radiative neutron capture for several resonance of Ta by measuring the slowing down time in lead with the help of a neutron spectrometer.

### *1.4 Astrophysical aspects of neutron physics*

#### 1.4.1 Measurement of the neutron capture cross section of the isotopes $^{22}$Ne, $^{30}$Si, $^{40}$Ar, $^{78,80,84,86}$Kr at astrophysical energies

Processing of the experimental data completed and analysis of the results of joint FLNP JINR - Forschungszentrum Karlsruhe experiments was carried out under the program of nuclear data for astrophysics. The experiments were conducted at the Van de Graaff accelerators in Karlsruhe and Tubingen, Germany. The reactions $^{7}$Li(p,n) and T(p,n) were used as a source of neutrons. The capture cross sections of isotopes were determined by the activation method. The cross sections for the neutron energy interval 25 – 215 keV were obtained. On the basis of the obtained data and available data on resonance parameters the Maxwell spectrum average capture cross sections were obtained for the temperature range corresponding to kT = 1 – 250 keV. In a number of cases, the new values differ appreciably from those recommended for astrophysical calculations (see **Fig. 7**). A qualitative analysis of the possible influence of the new data on various astrophysical scenarios of the production of elements was performed.

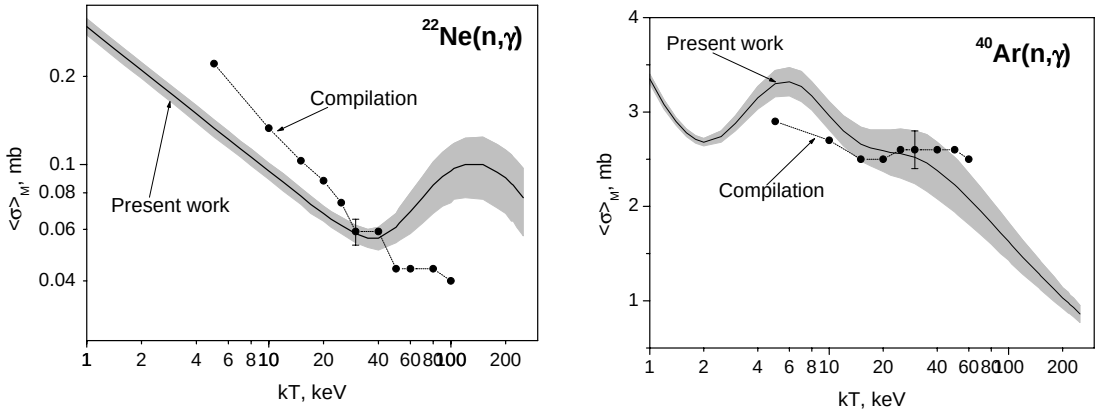


***Fig. 6.*** *The Maxwell distribution average cross sections obtained in this work in comparison with the recommended data.*

**1.4.2 Modeling of neutron nucleosynthesis in the region of sulphur and chlorine in the stage of hydrostatic burning of massive stars**

Work to model different scenarios of nucleosynthesis continues in cooperation with members of the University of Lodz, Poland. The earlier developed program for the calculation of neutron nucleosynthesis in the stage of hydrostatic burning of helium in stars with a mass of 25 $M_{\odot}$ is extended to the next stage of hydrostatic burning of carbon. The program is complemented with the possibility of determination of integral fluxes of reactions, analysis of branching points and contributions of the branches to the production of isotopes. Analysis of the formation of elements in the region S-Cl-Ar was performed accounting for the new data on neutron cross sections obtained for a number of isotopes. The dependence of the concentration of elements from the discussed region in the stage of He- and C-burning on time is calculated.

***1.5 Fast neutron-induced reactions accompanied with emission of charged particles***

The modernization of the detectors, electronic equipment and fast neutron channels at EG-5 in FLNP JINR started. The characteristics of the fast neutron beam with neutron energies from 3.5 to 6.5 MeV from the reaction d-D were studied. Another deuterium gas target as well as a lithium and a tritium targets will be created.

Under development is a technique of measurements of light nuclei whose investigation has a number of peculiarities and thus, the problem cannot be solved using the methods that were successfully applied to study nuclei of middle mass.

Two more problems, an understanding and separation of the background and correct accounting for distortions in the energy spectrum of the neutron source, are being solved.

When the chamber is irradiated with a fast neutron flux, in addition to signals from the charged particles from the investigated reaction and background reactions on construction materials there are also registered signals from the charged particles arising in the working gas. For the preparation of the experiment and the following procession of the results it is necessary to know to which region of the two-dimensional amplitude spectrum ($P_{Ан} \times P_{Kam}$) signals from the charged particles from the reaction of interest will come. To serve the purpose, a complex of programs modeling the processes going in the chamber has been developed.

For the purpose of a detail comparison of spectra obtained in the measurement and identification of particles, the spreading of signals due to the resolution power of the detector and changes in the energy of α-particles due to transmission through a substance layer of finite length as well as neutron energy spreading in the initial spectrum were taken into account in the calculation.

To this end, a program, which models the emitted neutron spectrum for a van de Graaff accelerator-based source, was written. Changes in the neutron spectrum due to transmission through a substance were calculated by the program MCNP. The experimental data obtained for the reaction $^{64}Zn(n,\alpha_0)^{61}Ni$ at the neutron energy $E_n$=5 MeV and the gas pressure Kr+4.71% $CH_4$ 1.2 atm are in good agreement with the model calculation. In the future, to test the correctness of the calculation, measurements of neutron spectra will be carried out at EG-4,5 in Peking University.

Work to build a measuring module for multiparameter measurements (with the prospect of using it at IREN) started in cooperation with physicists of the University of Lodz.

### *1.6 Nuclear data program*

#### 1.6.1 Investigation of the resonance structure of the neutron cross section of fission fragment and fissionable materials

In 2002 processing of the time-of-flight spectra of *Nb, Mo, Pb,* $^{235}U$, $^{239}Pu$ sample-filters measured earlier on the flight paths 122 m, 501 m or 1006 m of IBR-30 using multi-section detectors of neutrons and gamma-rays continued. After subtracting the background total and partial neutron group cross sections, resonance blocking factors of the total cross section and the scattering cross section of *Nb, Mo* and *Pb* in the energy range 0.100 eV to200 keV were determined from the time-of-flight spectra. The experimental error of cross sections and blocking factors is 3-7% and 8-15%, respectively. Analogous values were calculated on the basis of the estimated data from various libraries by the program GRUKON. On the whole, the calculated and experimental data coincide but in some energy groups, discrepancies are outside the experimental error limits.

For uranium-235 and plutonium-239 alpha values ($\alpha=\sigma_\gamma/\sigma_f$) in resolved resonances for the energy interval 1-1200 eV and in energy groups 20 eV - 10 keV were determined from the time-of-flight spectra of different coincidence multiplicity gamma-rays after subtracting background components. In addition, the Doppler effect in the value of alpha was **first** studied for plutonium-239 at the temperature 293 K and 77 K. The experimental error of the alpha value is from 2 to 30% in dependence on its resonance peculiarities. Alpha values were also calculated on the basis of the estimated data from various libraries by the program GRUKON. The difference between the calculated and experimental values reaches 50% in some resonances and energy groups.

#### 1.6.2 Total neutron cross section measurements

Under a FLNP JINR – PAL (Pohang Accelerator Laboratory) POSTECH (Pohang, Republic of Korea) collaboration the total neutron cross sections of Ag, Cu, Sm, In, Dy (natural mixture of isotopes) were measured. For Ag and Sm there were obtained the parameters of neutron s – wave resonances in the region 0.1 – 80 eV and for Sm and In similar parameters were obtained in the region up to 10 eV.

The measurements of the total neutron cross sections were performed on a vertical neutron channel in PAL by the time-of-flight method. The flight path was 10.8 m. In the experiments a mechanism for automatic replacement of samples developed and built in FLNP JINR (see **Fig. 8**) was used. The mechanism allows carrying out measurements of four samples, which are introduced in turn into the neutron beam. The inaccuracy of sample position fixing in the beam is less than 1 mm.

Neutrons were registered with the scintillation detector BC702/5 of Bicron Corp., (ZnS(Ag)) enriched with $^6Li$. To separate neutrons from gamma-rays (see **Fig. 9**), a scheme of n - γ separation created in 2001 on the basis of standard blocks produced by the company EG&G ORTRC was used. The scheme allows almost complete separation of pulses due to neutrons from those due to gamma-quanta with respect to the back front duration loosing not more than 15% of neutrons.

The total cross section data for Sm and In was processed in KAERI (Korean Atomic Energy Research Institute). The data for Ag and Sm were first processed in PAL by the program SAMMY-M2 and then sent to KAERI for possible further processing and inclusion into the neutron cross section library.

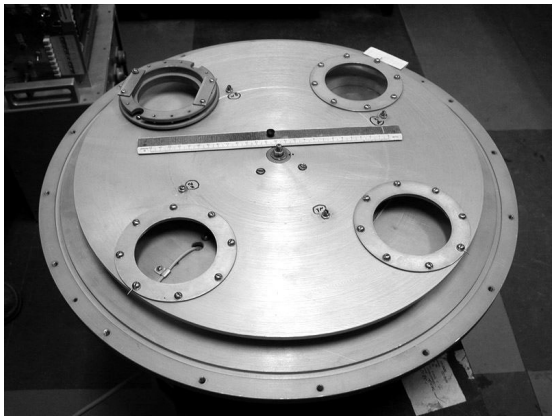

***Fig. 7.*** *The mechanism for sample replacement, the hermetic jacket being removed.*

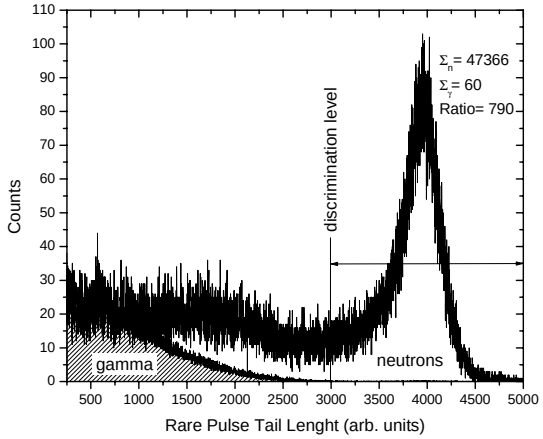


***Fig. 8.*** *Separation of pulses due to neutrons from those due to gamma-quanta with respect to the form (duration) of the back front. The arrow shows the length interval of the back front pulses transmitted through the scheme to accumulate time spectra.*

## *1.7. Fundamental properties of the neutron*

### 1.7.1 Investigation of the neutron charge radius

In the traditional research directions of the Scientific Experimental Division of Nuclear Physics (SEDNP) in FLNP investigating the electric polarizability and the mean square charge radius of the neutron in 2002 much attention was given to the study of the charge radius determined by the $n,e$-scattering length $b_{ne}$. Since the situation with the experimental values of $b_{ne}$ is quite ambiguous (there exist several dozens of values within an accuracy of $(0.03 \div 0{,}05)\cdot 10^{-3}$ Fm that group around $\sim -1.3\cdot 10^{-3}$ Fm and $\sim -1.6\cdot 10^{-3}$ Fm), it is very important to improve measuring methods and seek errors in the applied techniques.

It is suggested that $b_{ne}$ should be measured using the forward-backward scattering asymmetry of neutrons in argon determined by the time-of-flight method for different neutron energies. The total cross section of argon was determined for the neutron energy interval ~5 eV to 30 keV and all known cross sections of Ar and $^{36}$Ar for the energies beginning from thermal energies were analyzed. This allowed obtaining of a record accuracy of the nuclear scattering coherent length to total nuclear scattering cross section ratio

$$a_{coh}^{N} / \sigma_{s}^{N} = (0.0287 \pm 0.0001)\ \text{Fm}^{-1}$$

for natural argon. It is necessary for a reliable extraction of $b_{ne}$ from the results of future experiments.

A careful analysis of the results of the study of neutron scattering on noble gases by Krohn and Ringo, which has become a classical work, has revealed appreciable dependence of the observed scattering asymmetry on the pressure of krypton and xenon varied from 0.4 to 1.2 atm in [3]. This is very likely due to not accounting for the effect of neutron diffraction on a single-atom

gas. Krohn and Ringo's $b_{ne} = -(1.34 \pm 0.03) \cdot 10^{-3}$ Fm must be changed for $b_{ne} = -(1.24 \pm 0.06) \cdot 10^{-3}$ Fm if the discovered effect is taken into account. The question of neutron diffraction on a gas is thus of great importance and need to be studied carefully.

### 1.7.2 Experiments of direct measurements of the neutron-neutron scattering length at the pulsed reactor JAGUAR (Snezhinsk)

As part of the experiment preparation theoretical modeling of the processes of neutron-neutron collision in the central channel of the reactor, neutron scattering on a calibration gas and of neutron radiation propagation in the neutron channel continued.

The experimental data on the thermal neutron output from the different thickness moderators are in agreement with the modeling results. From the modeling it follows that the angular distribution parameters correspond to the isotropic source used in the analytical calculation of the number of collisions and the detector's counting rate.

The spatial distribution of thermal neutrons along the Z-axis of the channel is sensitive to the distribution of the reactor construction materials, which is also, though slightly, sensitive to the situation of the moderator relative to the center of the liquid active zone and changes as the level in the zone changes. The modeling of both reveals a distribution asymmetry similar to that observed in activation measurements.

The calculated energy spectrum of thermal and epithermal neutrons is in agreement with the conducted measurements. The model distribution of the flux density has a section of epithermal neutrons proportional to 1/E and a Maxwellian distribution of thermal neutrons with a most probable energy of 26 meV. The interrelation of the two parts of the spectrum corresponds to activation measurements.

Analytical calculation of the neutron field inside a through channel of the reactor was performed. The results on the neutron density agree with those of the modeling of the spatial neutron density distribution in the reactor by the Monte-Carlo method. The number of *nn*-collisions in the channel and the angular distribution of neutron scattering in the laboratory system of reference are calculated. The number of events of neutron scattering on the neutron and on calibration gases is calculated. The calculation is done for the Maxwell distribution of neutrons in velocity without taking into account possible contribution of epithermal neutrons and the effect of the nonstationary stage of neutron moderation.

Work to prepare the physical environment of the reactor necessary for carrying out the experiment started. An insert tunnel of 10 m to host the neutron channel and the detector was manufactured.

### 1.7.3 Neutron decay-related investigations (lifetime and correlation coefficient)

Several hydrogen-free fluoropolymers with a low melting temperature were investigated as to their possible use as a wall material of ultracold neutron traps with low neutron losses. Their viscosity at 150-300 K and neutron cross sections at 10-300 K for the neutron wavelengths 1-20 A were measured. Conclusions about their possible parameters as a material for ultracold neutron traps were made. The quasielastic reflection of neutrons from the surface of a viscid liquid is investigated in the framework of the Maxwell model and on the basis of PINP's published experimental results on UCN quasielastic scattering quantitative conclusions about the dynamical parameters of the liquid – rigidity and relaxation time – are made. This has formed a basis for joint experiments with the Univ. of Rhode Island, Harvard Univ., PINP, ILL, and Kyushu Univ. to investigate UCN quasielastic scattering on such liquids at low temperatures. Promising results were obtained giving hope to improve measurements of the neutron lifetime at their storage in traps.

The mechanisms of ultracold neutron depolarization in traps at their reflection from the walls are investigated. The first involves spin-flip at elastic or quasielastic scattering on hydrogen-bearing surface admixtures. A second says that appreciable neutron depolarization may occur even

at high adiabatic parameters in the process of neutron movement in an inhomogeneous magnetic field due to sharp changes in the neutron trajectory caused by neutron reflection from the walls.

### *1.8 Physics of ultracold neutrons, neutron optics*

#### 1.8.1 Investigation of supersmall energy transfer processes at interaction of ultracold neutrons (UCN) with solid body surfaces

Studies of the processes of small UCN energy transfer in the Large Gravitational Spectrometer (LGS) continued. LGS allows simultaneous observation of the stored UCN neutrons and the forming "excited" ultracold neutrons (EUCN) and enables the registration of EUCN over the energy range 50-150 neV with an effectiveness of ~50%.

In the reported year the differential spectra of EUCN and their dependence on the UCN spectrum for a stainless steel sample were obtained using the new facility. The temperature dependence of the probability of weak heating on samples from stainless steel, copper, and diamond nanopowder is obtained for the temperature range from 300K to 100K. The characteristic dependence of the weak heating probability on the surface of an A304 stainless steel sample on the temperature of preliminary degassing is obtained.

A pronounced process of weak UCN heating has been discovered for a sample of ultradisperse diamonds with a mean size of 50Å and no heating has been observed on the surface of a sapphire monocrystal within the sensitivity of the facility.

Additional investigations with a microscope of atomic forces showed changes in the nanostructure of the surface of the A304 stainless steel sample depending on the degassing temperature and the absence of surface nanoformations on the sapphire monocrystal.

The results obtained under the project point to the fact that the nature of weak UCN heating on solid body surfaces is connected with the interaction of UCN with surface nanoformations. The obtained results are an experimental indication of the possibility of building a fundamentally new high density UCN source based on the thermolization of cold neutrons due to nanostructures. It is the first time that the fundamental possibility of studies of the dynamics of nanostructures with the help of UCN was demonstrated using the built facility.

#### 1.8.2 Development of high-resolution differential UCN spectrometry

Experiments to develop the differential spectrometry of superlow energy neutrons by the time of flight employing the mechanic and magnetic modulation of the neutron flux in the pseudorandom mode were prepared and conducted.

The geometry and method for the measuring of spectra of the quasielastically reflected neutrons at energy transfers in the interval up to 200 neV and small scattering probabilities were proposed. The method involves the use of a threshold detector displaceable in the gravitational field. The achievable energy resolution is 3-5 neV. The Monte-Carlo modeling of the spectrometer operation was carried out.

## 2 Theoretical investigations

### *2.1 Theoretical investigations in reflectometry of multilayer systems*

There is jointly proposed the new method of the preparation of supermirrors that increases the total neutron reflection angle. The supermirror is designed as a combination of several periodical systems of bilayers with overlapping Bragg peaks. Such a system is analyzed analytically and the number of layer thickness chains and the number of periods in each chain are determined. The case when the critical angle increases 3.2 times is calculated. The calculation is done for an ideal system with and without accounting for losses in the layers. It is shown that to increase the critical angle 2 times, it suffices to have 12 chains and not more than 46 bilayers.

An analytical approach to the processing of the experimental data on thin film reflectometry taking into account smooth transitions at interfaces has been developed.

### *2.2 Problem of baryon charge nonconservation and search of neutron-antineutron oscillations with the help of ultracold neutrons*

The influence of the neutron collision with the wall on the process of neutron to antineutron transition was investigated and a comparison of the search effectiveness of neutron-antineutron oscillations in beam experiments and in experiments with ultracold neutrons is performed. The conditions in which the effectiveness of ultracold experiments could be higher than that of beam experiments by 2 orders of magnitude are outlined.

### *2.3 Investigation of weak one-nucleon interaction to P-odd nucleon-nuclear potentials and of spin effects in nuclear reactions*

Theoretical investigations of the weak one-nucleon Hartry-Fock potential $V_W^{HF}$ constructed on the basis of the weak *P*-odd *NN*-interaction continued. It is shown that the corresponding Hartry terms and the Fock terms of a zero order have a pronounced surface character. The indicated surface terms of the potential $V_W^{HF}$ were calculated for the nuclei $^{208}Pb$ and $^{40}Ca$ on the basis of a characteristic set of weak *NN*-forces.

The relationship between the cross section of the charge-exchange break-up of the deuteron $d + a \to (pp) + b$ and the differential cross section of the nucleon recharge reaction $n + a \to p + b$ was investigated. The dependence of the differential cross section of the process $d + p \to (pp) + n$ in the direction "forward" on the polarization parameters of the deuteron and proton was investigated. The influence of the *D*-wave state of the deuteron on the polarization effects and the spectrum of relative momentums of two protons were analyzed for the process $d + p \to (pp) + n$ in the direction "forward".

The transformations of the components of the correlation tensor in a system of two particles with spin 1/2 at transition of the pair of particles from the center of mass to laboratory system of reference were investigated taking into account the relativistic effect of spin rotation.

### *2.4 Theoretical investigations of neutron $\beta$-decay*

In the framework of the Standard Model radiative corrections to the $\beta$-decay of the neutron were calculated. The electroweak interactions were consistently taken into account in accordance with the Weinberg-Salam theory. The effect of strong interactions is parametrized by introducing the quantities $g_A$, $g_V$, $g_{WM}$ … as in the theory of $\beta$-decay by Fermi. The radiative corrections to the decay probability $W$ and the distribution asymmetry coefficient of electrons $A$ are $\delta W = 8\%$ and $\delta W \approx -2\%$, which is essential for the extraction from the experimental data of the weak theory characteristics, particularly of the element $V_{nd}$ in the matrix CKM.

### *2.5 Calculation of hypernuclei formation cross sections*

The calculation of the cross sections of the formation of the neutron-excess hypernuclei $^{12}_{\Lambda}$Be, $^{16}_{\Lambda}$C, and $^{10}_{\Lambda}$Li in the reactions $(\pi^-,K^+)$ and $(K^-,\pi^+)$ together with accounting for two possible formation mechanisms of such systems continued. The first is a two-step process with recharging (for example, $\pi^-p \to \pi^0 n$, $\pi^0 p \to K^+\Lambda$). The second is the one-step reaction of the formation of $\Sigma^-$ admixtures ($\pi^-p \to K^+\Sigma^-$) taking place in Λ-hypernuclei due to ΛN-ΣN mixing. In the majority of cases the two-step process appears to be more productive. The differential cross section for a zero angle in the reaction $^{10}B(\pi^-,K^+)^{10}_{\Lambda}Li(2^-)$ is about 70 nb/sr for the pion pulse 1.05 GeV/c. The estimation was made in connection with the staging of the corresponding experiment in KEK

(Tsukuba, Japan) in October, 2002. A preliminary analysis of the experimental data has only yielded an estimate of 10 nb/sr.

## 3. Analytical investigations at the IBR-2 reactor

### *3.1 Ecology*

In 2002 work to study atmospheric depositions of heavy metals by the biomonitoring technique, NAA and GIS technologies (REGATA project) over the territory of Central Russia (Tver, Yaroslavl and Northern Moscow regions) as well as a number of European countries (Bulgaria, Slovakia, Romania, Ukraine, Poland, Serbia, Bosnia) continued. The results of the investigations are contributed to the European Atlas published under UN. Analogous works are being carried out in South Korea, China, Macedonia and Turkey. In November 2002 the IEAE project for investigations in the Southern Ural region, whose goal was the assessment of the contamination of the Chelyabinsk region with heavy metals and radionuclides completed having analyzed over 1500 analyzed.

Work to investigate the contamination of soils with heavy metals and other toxic elements due to over-the-road transport (Minnesota, USA) completed having analyzed 200 samples. A total of 250 air filters were analyzed to study the air quality in the tube in London. The method of fluorine identification in air filters was tested at IBR-2 for the first time. In cooperation with the Geological Institute, RAS there was carried out a comparative analysis of the element composition of a number of food products grown in the condition of strong antropogenic influence in the deltas of the Volga and the Nile (Egypt) (300 samples).

In 2002 the first stage of the project «Monitoring of Workplaces and Health of Personnel Engaged in Phosphor Fertilizer Production at Plants in Russia, Uzbekistan, Poland, and Romania» (European Program 5 Copernicus) completed. The results of an analysis of ecological samples, including raw materials, soils, sediments, water, and filters, and of human biosubstrates like hair, nails, urine, and teeth, were discussed by the participants of the project at meetings in Dubna and Gdansk.

### *3.2 Materials science*

The impurity elements content of 300 samples of diamonds artificially grown in the Institute of Solid State Physics and Semiconductors of the National Academy of Sciences of Belorussia in Minsk was studied. Also, samples of superpure silicon developed by the Institute of Crystallography in Moscow were irradiated. An analysis of 20 archeological ceramic samples from Romanian museums was carried out what will allow the determination of their origin.

### *3.3 Biotechnologies*

The work carried out in cooperation with a group of biophysicists from the Institute of Biophysics of the Academy of Sciences in Georgia to develop pharmaceuticals based on the blue-green alga *Spirulina platensis* continued. The NAA method was applied to study the composition of the pharmaceuticals extracted from the spirulina biomass (DNA and C-phycocyanin). The peculiarities of the interaction of the microalga with Cr(III) and Cr(VI) and of a combined effect of chromium and selenium on the spirulina were studied.

In 2002 investigations of the composition and behavior of another microorganism – *Arthrobacter oxidants* – with the aim of studying the possibility of its application for the purposes of biotechnology started.

Together with Tbilisi Technical University we completed a cycle of works to substantiate the use of peat suspensions for bacterial leaching out of some metals from rocks, ores, and industrial wastes as well as the application of natural sorbents (tea, moss, etc.) for the extraction of metals from the leached solutions.

# 2. NEUTRON SOURCES

## 2.1. The IBR-2 Pulsed Reactor

In the 2002 the IBR-2 reactor operated in accordance with the approved working schedule. It operated 8 cycles (2133 hr) at W=1,5 MW for physical experiments with 3 cases of emergency shutdowns by the automatic emergency system (AES). The details of the IBR-2 operation are summarized in Tables 1 and 2.

*Table 1*

**The operation parameters of the IBR-2 reactor in the period from January 1, 2002 to January 1, 2003**

| **Cycle №** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | ***TOTAL:*** |
|---|---|---|---|---|---|---|---|---|---|
| ***Time of cycle*** | *14.01 - 25.01* | *11.02 - 22.02* | *11.03 - 22.03* | *08.04 - 19.04* | *13.05 - 24.05* | *21.10 - 01.11* | *11.11 - 22.11* | *02.12 - 13.12* | |
| Operation for physical experiment, hr | 265 | 264 | 263 | 260 | 262 | 267 | 267 | 265 | **2113** |
| Operation of movable reflector, hr | 274 | 275 | 276 | 272 | 274 | 276 | 276 | 276 | **2199** |
| Generated power, MW·hr | 400 | 378 | 397 | 394 | 397 | 403 | 403 | 400 | **3172** |
| Number of emergency shutdowns (AES) | – | – | 1 | 1 | 1 | – | – | – | **3** |
| Due to: | | | | | | | | | |
| ▪ Voltage drops | – | – | 1 | 1 | 1 | – | – | – | **3** |
| ▪ Instrumental malfunction or failure | – | – | – | – | – | – | – | – | **0** |
| ▪ Electronic equipment failure | – | – | – | – | – | – | – | – | **0** |
| ▪ Personnel error | – | – | – | – | – | – | – | – | **0** |

*Table 2*

**The IBR-2 parameters as of 01.01.2003**

| **№** | **Parameter (counted from the start of reactor operation)** | **Actual** | **Rated** |
|---|---|---|---|
| 1 | Total operation time for physical experiment, hr | 42746 | |
| 2 | Total generated power, MW·hr | 77690 | 85000 |
| 3 | Mechanical operation time of the movable reflector MR-2P, hr<br>Radiation generation by MR-2P, MW·hr<br>*(with the flux density over the center of the blade $5 \cdot 10^{13}$ n/cm$^2$·MW for neutrons with E>0,1 MeV)* | 18268<br><br>30462 | 19000<br><br>36000 |
| 4 | Maximum fluence on the reactor jacket in the center of active zone ($10^{22}$ n/cm$^2$):<br>• for En > 0,1 MeV<br>• for En > 0,8 MeV | <br>3,36<br>1,45 | <br>3,72 |
| 5 | Maximum fuel burn, (%):<br>• for pellet TVELs<br>• for spigot TVELs | <br>5,8<br>6,3 | <br>6,5<br>8,2 |
| 6 | Reactivity resource, (%) | 0,47 | |
| 7 | Total number of emergency shutdowns | 441 | 550 |

## Main results of the IBR-2 modernization in 2002:

### *1) MR-3 – chief task of the year*

1.1. JINR EW :

- Manufacturing of the MR-3 parts is completed in the main.
- Test assembling of the manufactured parts (carriage, platform, technological frame, dismountable shielding) and elimination of faults are under way.
- Working assembling of the reduction gearbox is carried out.

1.2. NIKIET

- Main reactivity modulator was manufactured and handed over to FLNP.
- Auxiliary reactivity modulator is planned to be completed by 30.12.2002.
- Manufacturing of the jacket is delayed due to the technological problems, which arose during its welding.

### *2) New fuel assembly*

2.1. Manufacturing of $PuO_2$ pellets is in progress at the Industrial Enterprise «Maiak» (~ 50 %).
Date of TVEL completion was corrected – 2nd quarter of 2003.
2.2. Manufacturing of the fuel assembly parts was started.
2.3. Investigation of two used fuel assemblies from IBR-2 was completed in NIKIET.

### *3) Working documentation*

3.1. Working design of a new jacket for the IBR-2M reactor was completed, working drawings were handed over for manufacturing.
3.2. Detail designing of stationary reflectors, rolling shieldings, etc. was started.
3.3. Project of works to disassembly the existing jacket of IBR-2 was completed, project of works to assembly a new jacket of IBR-2M was started.

### *4) CSS*

4.1. A full-scale test-bench was created in FLNP to study the automatic emergency system motor drive of the IBR-2M, first investigations proved the efficiency of the technical project solutions in the speed of response of the automatic emergency system (AES).
4.2. Search for cheaper variants to create electronic equipment was continued.

### *5) Helium facility*

5.1. Engineering design of a special helium facility for the cold moderator was completed.
5.2. Detail designing is in progress.

To provide the above-mentioned works a sum of about 553 k$ was spent in 2002, according to the plan 700 k$, including JINR – 130 k$ (according to the plan 250 k$), MAE – 423 k$ (according to the plan 450 k$).

## Plan for the modernization of IBR-2 in 2003

### *1. MR-3 (chief task):*

- test assembling of MR-3 and bench tests;
- moving of MR-3 to bldg. 117, its assembling and tests at a regular place.

### *2. Fuel assembly of IBR-2M:*

- completion of manufacturing of TVELs,
- manufacturing of the fuel assembly parts.

3. ***Development of design documentation:***
    - working documentation for the IBR-2M reactor equipment,
    - project of works to assembly the new jacket of IBR-2M.
4. ***Manufacturing of the IBR-2M reactor jacket.***
5. ***Development of the design of CSS electronic equipment.***
6. ***CHF:***
    - completion of the working design;
    - manufacturing of CHF.

## 2.2. The IREN Project

The plans of activity for 2002 included three main items:

1. Preparation for full decommissioning of the IBR-30 reactor.
2. Completion of the approved part of the IREN working project and creation of the design documentation for manufacturing the multiplying target.
3. Manufacturing of elements of the LUE-200 accelerator and start-up of its dismantling in bldg. 43 of FLNP.

The detailed time-tables for realization of this program were prepared in FLNP and LPP together with external partners involved in the implementation of the project. These documents were presented to the JINR Directorate together with the request for necessary funding in the amount of 570K$. After consideration of financial possibilities of JINR, a special grant of the Directorate at the rate of 380 K$ was allocated for realization of the project. In the first half of the year the work schedule and financial plan were executed with a delay of no more than one quarter, and by July 15 about 180 K$ was invested, which made it possible to cover debts for 2001 and to pay for necessary materials and works under contracts. But in the following period payments became irregular and insufficient to purchase equipment and to ensure the continuation of activity both in the Laboratories of JINR and in external organizations.

In spite of lack of financing many items of the plan of IBR-30 decommissioning were fulfilled. In particular, the construction of building 117/6 for storing activated elements of IBR-30 was practically completed by the end of 2002. However, because of the delay in purchase of the dosimetric equipment and creation of the physical protection system of the building, its official commissioning, including licensing, is shifted to the second quarter of 2003. The most part of the equipment necessary for dismantling the active zone of IBR-30 was designed and manufactured in the JINR Experimental Workshop. Two test-benches intended for training the personnel who should perform the most important and “dirty” operations in the course of the reactor dismantling were equipped and officially accepted for operation. In October, 2002, a special commission of Gosatomnadzor inspected the state of affairs and compliance with the terms of the license for decommissioning of IBR-30 and approved the realized part of the program. However, in the inspection report the delay in the fulfillment of the work schedule for at least four months was noted. Nevertheless, works to dismantle the reactor can be started in July, 2003, providing the allocation of necessary funds.

The contracts concluded with NIKIET, Moscow, in the first quarter of 2002 to work out the design documentation for manufacturing of the IREN multiplying target and to create a technical project of the control system for the facility were actively executed, in spite of lack of financing. The technical specification for the control system was prepared in close cooperation of experts from JINR and NIKIET and agreed with all involved services of JINR. More difficult situation was with the completion of the working project of the IREN facility developed by GSPI, Moscow. After a number of shifts the agreement was achieved that the approved part of the working project should be completed in May, 2002. However, the preliminary version of this document was submitted for approval to JINR only in October.

Even in conditions of irregular and deficient financing the work schedule to create systems for the linac LUE-200 was fulfilled only in the part implemented by the JINR Laboratories. A very difficult problem of advanced development of the design documentation necessary for manufacturing of elements of the LUE-200 accelerator was solved by the LPP and FLNP design offices. Design engineering of all elements of the linac located in the accelerating halls of bldg. 43 of FLNP was completed. We managed to complete the manufacturing of the farm for the accelerator, and also of some elements of the magnetic focusing system. However, works to manufacture the power supply system of the solenoid and some elements of the HF systems executed in BINP, Novosibirsk, are carried out with a considerable delay for lack of financing.

More favorable situation was with the tests of the HF system on a full-scale test-bench. The ten-day session of continuous operation of the modulator with a klystron at HF power level of no less than 70 % of the design value was successfully conducted. All elements of the HF feeder were tested and certified. A part that had no necessary parameters was given to the manufacturers for reconstruction. The electron source was assembled on the test-bench and will be tested in January, 2003. The designing of the control system of the accelerator was completed. A part of the equipment necessary for creation of this system was purchased and tested in the structure of the control system of the HF full-scale test-bench. A considerable part of quadrupole lenses was produced in the workshop of LHE. First two modules of the solenoid were manufactured in LPP for testing and certification on the test-benches of precise magnetic measurements in LPP and DLNP. The majority of elements of the linac vacuum system were tested and prepared for installation in bldg. 43.

It should be noted that the works conducted in the JINR Laboratories were remunerated from a special bonus fund allocated by the JINR Directorate. Without this support it would be impossible to perform design works, to dismantle auxiliary systems of the IBR-30 reactor, to start repairing the accelerating halls in bldg. 43 and to realize the most part of works on creation of the elements of LUE-200.

The total investments volume in the project by the end of 2002 was 312 K$, including payment to EW JINR for works that will be completed in 2003.

Summing up the fulfillment of the IREN project in 2002, it should be noted that the work schedule was only partially executed. The backlog is two quarters, on the average. So, the start-up of the linac is possible in 2004 and the completion and start-up of the first stage of the IREN project is shifted for 2005. The specified dates can be met providing the availability of necessary funds within the next three years.

# 3. THE IBR-2 SPECTROMETERS COMPLEX AND COMPUTING INFRASTRUCTURE

In 2002, work under theme 1012 was carried out in accordance with the FLNP projects: MCC, FSD, YuMO, Texture, SPN, as well as the BMBF-JINR projects: Detectors and ECS.

Main directions of activity:

1. development of the information and computing infrastructure;
2. creation of data acquisition and control systems of the IBR-2 spectrometers;
3. development of the IBR-2 spectrometer complex:
   - automation of spectrometers and development of sample environment systems;
   - creation of neutron detectors;
   - routine maintenance of spectrometers.

**1. Local area network.** In the FLNP local area network (LAN) the router of information flows CISCO 8510 was installed and put into operation. For direct connection of the SUN-cluster servers via twisted pairs the 8-port interface CISCO C85FE-8-16K was purchased. In buildings 117 and 44 the high-speed commutators Catalist 29XX (CISCO) were installed and connected to the central segment of the network via optical communication lines. All the network printers of the Laboratory that exhausted their resource were replaced. The logical reconfiguration of LAN was conducted and a changeover to new versions of the network software was carried out.

The completion of the first stage of the specified works on the LAN modernization made it possible:

— to increase real throughput of the network by 50-60 % without changing physical interfaces;
— to provide mechanisms of control, analysis and filtration of the network traffic;
— to extend address space (at present, up to 4000 IP-addresses);
— to organize virtual subnetworks for groups of users (or spectrometers) irrespective of their geographical location (in 2002, four subnetworks were created: NP, CMP, SEDSC and IBR-2 reactor building);
— to provide a guaranteed passband for the most important network applications (for example, for concrete spectrometers).

**2. Data acquisition systems.** Work to modernize detector electronics and to optimize characteristics of the VME data acquisition systems at the IBR-2 spectrometers (DN-2, YuMO, DN-12, EPSILON) was performed.

In cooperation with HMI, Berlin, a new version of the unified TDC/DSP DAG block for acquisition and accumulation of data from position-sensitive detectors with delay line data readout, was developed and manufactured. In the block, the determination of X/Y coordinates of the event (by signals from both ends of the delay lines) and neutron time of flight from the reactor start to the moment of detection, is executed; for the methodical purposes the amplitude of signals is measured as well. Two main operating modes are provided: histogram (on-line sorting of data and building of spectra) and "list" (accumulation of raw data with subsequent off-line processing). It is also possible to simultaneously accumulate histograms (for controlling the experiment) and to write raw data. The TDC/DSP block has a PCI-interface and is installed directly in the case of PC. At present, the adjustment of electronics and debugging of microprograms (DSP) of the block are under way.

For this block the architecture was developed and the debugging of the prototype of the program driver was carried out. The driver provides interaction between the program modules of the low (DSP) and following (PC) levels for several variants of basic software packages: C++, PV-WAVE, ROOT (for more details see Experimental Reports).

New low-noise preamplifiers for MWPC and point detectors, as well as read-out electronics for scintillation detectors ASTRA were developed. Four multiprocessor blocks of RTOF-analyzers (16 channels) were adjusted.

The development of the unified software for the Fourier-diffractometers was completed and its testing on FSD is in progress.

The concept of a new generation of the software for data acquisition and control systems of spectrometers on the basis of VME-PCI adapters was worked out. The interface programs were developed and their trial operation is carried out on the NERA-PR spectrometer (for more details see Experimental Reports).

For the SPN spectrometer the programs for positioning the polarizer and controlling current sources were developed. The open G2 program was supplemented by new possibilities for processing data from YuMO and SPN.

In the reported year, work to improve and provide service support of the software of the data acquisition and accumulation systems on all IBR-2 spectrometers, was conducted.

## 3. Development and routine maintenance of the IBR-2 spectrometer complex.

### *3.1. Development of sample environment systems.*

On the YuMO spectrometer the system consisting of 2 ring replaceable collimators based on step motors under control of the program of experiment **(Fig. 1)** was put into operation.

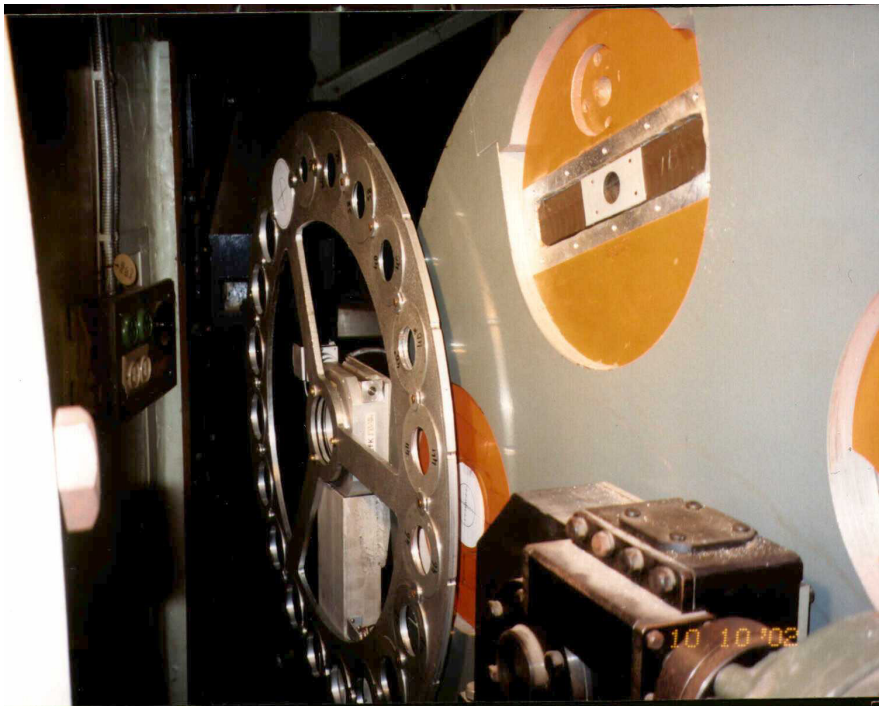

***Fig.1.*** *Two ring replaceable collimators at the YuMO spectrometer.*

Work to modernize the control systems of choppers based on microcontrollers **(Fig. 2)** was performed for the spectrometers: YuMO, HRFD, REFLEX (chopper and monochromator) and SPN (two choppers).


***Fig.2.*** *Chopper controller.*

The closed cycle cryostat КГУ801 for reaching a temperature of 4.2K (**Fig. 3**) was developed. The cryostat КГУ801 based on the two-stage cryogenerator RGD1245 makes it possible to obtain a constant temperature at the sample of about 4.2K using the Joule-Thomson stage.


***Fig.3****. Closed cycle cryostat КГУ801 on the basis of two-stage cryogenerator RGD1245.*

A high-pressure chamber of the "toroid" type for conducting neutron diffraction investigations of structure and lattice dynamics of condensed matter was created. The volume of a studied sample is 60-100 $mm^3$. The chamber was graduated using the manganin pressure sensor and by the known equations of reference material state. The maximum pressure in the chamber was 10GPa, which is a record in lattice dynamics research.

*3.2. Creation of neutron detectors.*

In 2002, research and development of different types of neutron detectors for the IBR-2 spectrometers were carried out.

- For the FSD diffractometer, 8 working elements of wide-aperture scintillation (ZnS) ±90º-detector with time focusing ASTRA were produced, tested and put into operation. Tests have demonstrated a high quality of manufacture and complete compliance of detector parameters with the calculated values. The solid angle of each module was increased by a factor of 2 as compared with the experimental model.

- To upgrade the detector system of the DN-12 spectrometer, the method of "rough" time focusing was suggested, which makes it possible to create economical detectors with a large solid angle for classical time-of-flight spectrometers with a large flight path. The method provides for a considerable solid angle with the help of economical small-area detectors. Thus, a high resolution of the spectrometer is ensured.

- Under the contract with IPM RAS (Nizhni Novgorod, Russia) microstrip structures with a “virtual cathode” were manufactured on special glass substrates (made of glass Schott S8900) with electron conductivity. The strip layout and coordinate readout using the division of charge from two ends of a resistive wire, are analogous to the Bidim80 detector developed and constructed in ILL. These structures were tested in ILL. The results of the tests have demonstrated a high quality of the microstructures and their suitability for use in neutron detectors. At present, two glass substrates with microstrip structures manufactured in IPM are in ILL and will be used in the operating detectors to check their long-term characteristics. One substrate is installed in the body of the detector manufactured in FLNP and prepared for tests..

- In collaboration with EMBL and LNP JINR the construction of a stand for creating proportional multiwire neutron detectors was started. The equipment to control the pitch of wire winding was purchased. The stand for testing MWPC detectors with delay line data readout was equipped with electronics.

- The prototype of the medium resolution multiwire detector with individual signal readout from every wire was designed and constructed. The detector working area is 8×8 $cm^2$. The distribution of counts from neighboring wires for X and Y planes is presented in **Fig.4**.

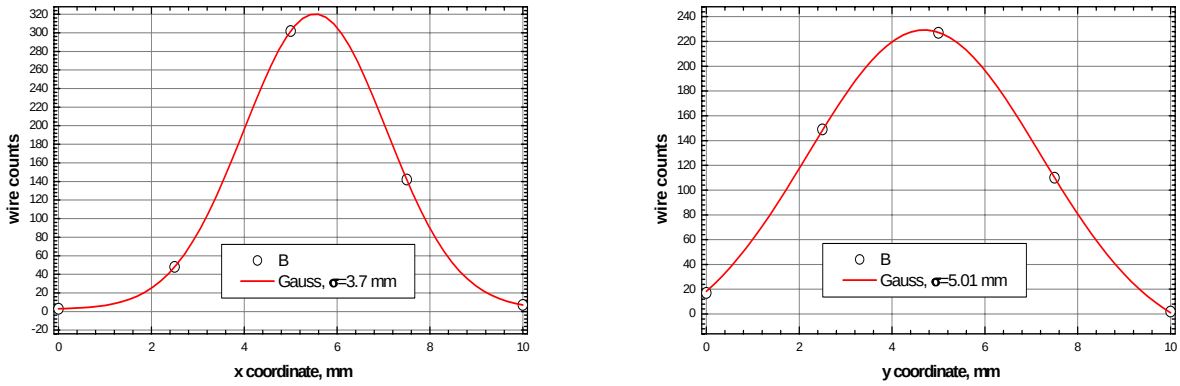


***Fig.4**. Distribution of counts from neighboring wires for X (left) and Y (right) planes of the detector exposed to a collimated alpha-particle beam.*

In the reported year, the equipment of spectrometers was prepared for operation and serviced for conducting experiments in 8 cycles of the IBR-2 reactor.

# 4. EXPERIMENTAL REPORTS

## 4.1. CONDENSED MATTER PHYSICS

### Diffraction

Simultaneous Doping of A- and B-Sites of $NdMnO_3$ by Sr and Ru: Suppression of Metallic State and Appearance of Unusual "Ferromagnetic" Structure
*A.M.Balagurov, S.N.Bushmeleva, V.Yu.Pomjakushin, D.V.Sheptyakov, V.A.Amelichev, O.Yu.Gorbenko, A.R.Kaul, E.A.Gan'shina*

Comparative Study of the Magnetic Phase Diagram of $(La_{1-y}Pr_y)_{0.7}Ca_{0.3}MnO_3$ with Oxygen Isotopes $^{16}O$ and $^{18}O$
*A.M.Balagurov, V.Yu.Pomjakushin, D.V.Sheptyakov, N.A.Babushkina, O.Yu.Gorbenko, A.R.Kaul*

Structural Study of Pressure-Induced Magnetic Phase Transitions In Manganites $Pr_{0.7}Ca_{0.3}Mn_{1-y}Fe_yO_3$ ($y$ = 0, 0.1)
*D.P.Kozlenko, V.P.Glazkov, I.V.Medvedeva, B.N.Savenko, V.I.Voronin*

Investigation of Non-Equilibrium Effects on Residual Stress State of Metallic Composites
*J.Schreiber, V.Richter, K.Voigt, G.Bokuchava, A.Tamonov*

Study of Residual Stresses in Bimetallic Adapter Steel-Zirconium
*V.Sumin, A.Tamonov*

Synthesis and examination of new phosphates of $K_2LnZr(PO_4)_3$ (Ln=Ce-Yb,Y)-type with langbeinite structure and $Fe_{0.5}Nb_{1.5}(PO_4)_3$ phosphate with kosnarite structure
*I.G.Trubach, A.I. Orlova, A.K.Koryttseva, M.V.Zharinova, Ye.V.Lipatova, V.A.Orlova, A.I.Beskrovnyi, A.N. Lukinih, V.S.Kurazhkovskaya*

Neutron Diffraction Used for Strain Scattering across a Shock-Deformed Quartzite/Dunite Interface
*K.Walther, A.Frischbutter, Ch. Scheffzük, T.Kenkmann*

Anisotropy of Archean Rocks from the Kola Superdeep Borehole on the Basis of Texture Analysis by Neutron Diffraction
*N.V.Zamyatina, T.I.Ivankina, A.N.Nikitin*

### Small-Angle Scattering

SANS Study of Molecular-Colloidal Solutions of $C_{60}$ Fullerenes in Water
*M.V.Avdeev, V.L.Aksenov, G.V.Andrievsky, L.I.Derevyanchenko, V.K.Klochkov, A.A.Khokhryakov*

From SANS Investigations of Mechanism of a Membrane Protein Crystallization to a Molecular Basis for Transcell Signalling
*V.Gordeliy, R.Efremov, R.Moukhametzianov, G.Bobarykina, A.Islamov, A.Kuklin, J.Klare, M.Engelhard, G.Bueldt*

SAXS Study of Trehalose Influence on the DMPC Vesicle Structure
*M.A.Kiselev, I.V.Gapienko, J.Perez, C.Bourgaux*

Investigation of Structure of Elongation Factor eEF-1A of Rabbit Liver by Neutron Scattering and Microcalorimetry

*I.Serdyuk, T.Budkevich, A.Timchenko, E.Tiktopulo, A.El'skaya, B.Negrutskii, V.Shalak, Z.Petrushenko, V.Aksenov, R.Willumeit, I.Kohlbrecher*

Small-Angle Neutron Scattering Study of the Bilayer Thickness in Unilamellar DOPC Liposomes Prepared by the Cholate Dilution Method: *n*-Decane Effect
*D.Uhríková, N.Kučerka, A.Islamov, A.Kuklin, P.Balgavý*

Self-Assembly of Polyelectrolyte Rods in Polymer Gel and in Solution: Small-Angle Neutron Scattering Study
*Yu.D.Zaroslov, V.I.Gordeliy, A.I.Kuklin, A.H.Islamov, O.E.Philippova, A.R.Khokhlov, G.Wegner*

**Inelastic Scattering**

Structure and Possible Cluster Formation in Liquid Lead-Potassium Alloys
*N.M.Blagoveshchenskii, Yu.V.Lisichkin, V.A.Morozov, A.G.Novikov, V.V.Savostin, A.L.Shimkevich*

Structural Phase Transition and Lattice Dynamics of Solid Mesitylene
*I.Natkaniec, K.Hołderna-Natkaniec*

The Investigation of ammonium Ion Dynamics in $K_{1-x}(NH_4)_xBr$ Mixed Crystal
*L.S.Smirnov, I.Natkaniec, V.Yu.Kazimirov, V.V.Dolbinina, L.A.Shuvalov*

**Neutron Optics**

New Composite Materials: Magnetic Nanoparticles in Copolymer Films by Specular and off-Specular Neutron Scattering
*V.Lauter-Pasyuk, H.J.Lauter, V.Aksenov, W.Petry, G.P.Gordeev, P.Müller-Buschbaum, B.P.Toperverg, A.Petrenko*

## 4.2. NUCLEAR PHYSICS WITH NEUTRONS

**Ultracold Neutrons**

Experimental Observation of the UCN Focusing in Time
*A.I.Frank, G.V.Kulin, A.N.Strepetov, P.Geltenbort*

The Reason for Small Changes in Energy of Ultracold Neutrons (UCN) in Traps
*E.V.Lychagin, D.G.Kartashov, A.Yu.Muzychka, V.V.Nesvizhevsky, G.V.Nekhaev, A.V.Strelkov*

**Parity Violation**

Recent Results on the Measurements of the P-odd Correlations in the Capture of Slow Polarized Neutrons by $^{6}$Li and $^{10}$B
*Yu.M.Gledenov, P.V.Sedyshev, V.A.Vesna, E.V.Shulgina, V.V.Nesvizhevsky, A.K.Petukhov, T.Soldner, O.Zimmer*

**Nuclear Spectroscopy**

On the Reliability of the Model-Independent Extraction Results of the Level Density and Radiative Strength Functions from the (n, 2γ) Reaction
*A.M.Sukhovoj, V.A.Khitrov*

**Applied Research**

Study of Element Composition of *Arthrobacter Oxydans* by Epithermal Neutron Activation Analysis
*M.V.Frontasyeva, S.S.Pavlov, S.F.Gundorina, L.M.Mosulishvili, Ye.I.Kirkesali, N.Ya.Tsibakhashvili, H.-Y.N.Holman*

## 4.3. IBR-2 SPECTROMETERS COMPLEX AND COMPUTING INFRASTRUCTURE

**Methodics**

Detector System on the Basis of Multiwire Proportional Chambers
*A.A.Bogdzel, A.V.Belushkin, V.V.Zhuravlev, F.V.Levchanovskii, E.I.Litvinenko, V.I.Prikhodko, V.N.Shvetsov*

Modernization of Spectrometer Control Systems Based on VME-PC Adapters
*A.S.Kirilov, E.I.Litvinenko, V.I.Prikhodko*

Scintillation Detectors with Geometric Focusing for Diffractometry
*E.S. Kuzmin*

# SANS STUDY OF MOLECULAR-COLLOIDAL SOLUTIONS OF $C_{60}$ FULLERENES IN WATER

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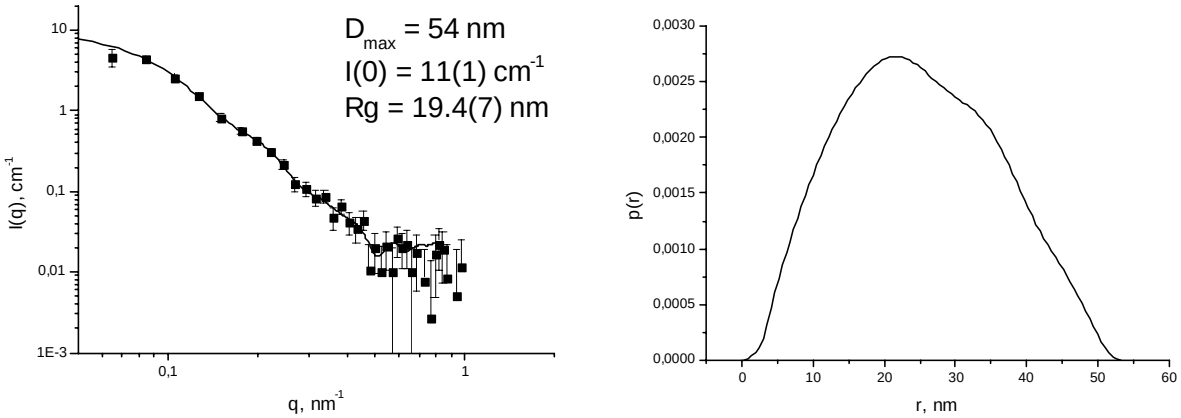
Since the discovery of fullerenes (1985) their biological activity was a question of particular interest. As a consequence, biological effects of fullerenes were actively studied for the last 10 years. This kind of investigations is connected mainly with the so-called "water-soluble" fullerenes — hydrophilic chemical derivatives of fullerenes. This approach was determined by a commonly accepted opinion that fullerenes are typical hydrophobic molecules and cannot form true solutions in water. However, starting from 1994 Andrievsky G.V and co-workers developed [1,2] a method of fabricating aqueous molecular-colloidal solutions of $C_{60}$ fullerene ($C_{60}$FWS) with the properties of both true and colloidal solutions simultaneously. This method is based on the transferring of fullerene from an organic solution into the aqueous phase with the help of ultrasonic treatment. The resulting dispersion is stable and has a significant therapeutic effect when treating experimental pathologies [3,4]. The mechanism of this effect is assumed to be quite different from that of other antioxidants.

In the present work the small-angle neutron scattering (SANS) is applied to study the structure of $C_{60}$FWS which was produced without resort to any solubilizers and chemical modification. The aim of the experiments was to clarify the mechanism of stabilization for $C_{60}$FWS basing on the information about the inner structure of the colloids. Experiments were carried out on the YuMO setup at the IBR-2 pulsed reactor at room temperature (20$^o$C). The scattering curves were obtained in a q-interval 0.007÷0.15 Å$^{-1}$. In the studied samples of $C_{60}$FWS the $C_{60}$ concentration was from 0.002 to 0.2 mM (0.0014÷0.14 mg/ml). Experiments were repeated twice for samples of different time preparation and showed a full reproducibility.




*a*) *b*)

*Fig.1. Typical small-angle neutron scattering curve (a) and the pare distance distribution function (b) for $C_{60}$FWS, c = 0.192 mM, T = 20$^o$C.*

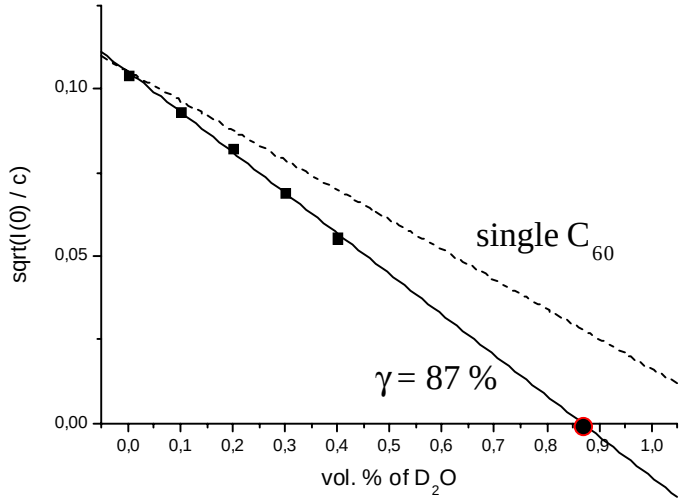



*Fig. 2. Contrast variation for $C_{60}$FWS, c = 0.192 mM, T = 20°C; γ is the match point of the system corresponding to relative content of $D_2O$ when the scattering from the aggregates disappears. Dashed line corresponds to behavior of the contrast as if fullerenes are single.*

The SANS curves (Fig.1) show that these systems are highly polydisperse in a wide scale interval up to 50 nm, which testifies the electron microscopy data [5]. The attempts to obtain the stable size distribution function of aggregates using the uniform spherical form-factors fail. Along with it the contrast variation (Fig.2) performed by diluting $C_{60}$FWS with heavy water points to the presence of a component in the aggregates, which is different from fullerenes and is assumed to be responsible for the stabilization of the solutions. The origin of this component, in particular the hypothesis about the formation of a specific hydration shell around fullerenes [2], is under discussion now. It should be pointed out that in general the structure of the studied systems is very close to that of the system $C_{60}$/pyridine/water where the role of stabilizer plays a thin pyridine shell around fullerene complexes [6, 7]. Also, the structural changes after the coagulation which takes place in the solutions on addition of salts were determined and are under analysis at the moment.

The work was carried out with the support of the Russian Ministry of Industry, Science and Technologies, state contract №40.012.1.1.1148.

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# FROM SANS INVESTIGATIONS OF MECHANISM OF A MEMBRANE PROTEIN CRYSTALLIZATION TO A MOLECULAR BASIS FOR TRANSCELL SIGNALLING

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Membrane proteins, residing in lipid bilayers are responsible for vital processes in the cells such as transformation of energy, solute transport, charge separation as well as signal transduction. Understanding of such fundamental processes at a molecular level requires knowledge of the structures of these proteins at high resolution. Crystallographic methods need well-ordered three-dimensional crystals, but it is extremely difficult to obtain proteins of this class in suitable crystalline forms.

Landau and Rosenbush proposed a novel approach for crystallizing membrane proteins in a lipidic cubic phase (Landau *et al*., 1996). This system, consisting of lipid, water and protein in appropriate proportions, forms a structured, transparent and complex three-dimensional lipidic array, which is pervaded by an intercommunicating aqueous channel bicontinuous system. Such matrices provide nucleation sites and support growth of the crystals. This method of crystallization in the cubic phase was successful in the crystallization of an important membrane protein - bacteriorhodopsin (BR) ( Pebay-Peyroula *et al*., 1997). However, it was not clear whether the crystallization of membrane proteins in the lipidic cubic phase is a general method. Moreover, in spite of the attempts to study its mechanism of crystallization (Nollert *et al*., 2001; Caffrey, 2000), it is an open problem why the lipidic cubic phase promotes the crystallization of the membrane proteins.

One of main aims of this work was to study in detail the kinetics of phase behaviour of protein/lipid cubic phase/buffer system (proteolipidic cubic phase) in the course of BR crystallization. This investigation is necessary to understand how general is the behaviour of the cubic phase in those cases where BR crystals grow and to answer the question about necessity of phase transitions for protein crystallization, since it was believed that the phase transition could be a key step in the crystallisation. In the present work detailed kinetics of the proteolipidic cubic phase behaviour was studied by SANS at small angle neutron scattering spectrometer YuMO (FLNP, JINR, Dubna, Russia) in the range from 0.01 $Å^{-1}$ to 0.4 $Å^{-1}$ ($Q=4\pi \sin\theta/\lambda$) at the standard crystallization conditions (Landau *et al*., 1996). It was found that in spite of significant influence of the protein on parameters of the lipid cubic phase caused by salt addition (Fig.1), the Pn3m symmetry of the cubic phase -monooleoyl-*rac*-glycerol (monoolein, C18:1c9) remains unchanged during the entire crystallization process. It was shown that coexistence of the “macroscopic” amount of the other phases as well as the presence of a phase transition is not necessary for the crystallization process (Gordeliy et al., 2002, Bobarikina et.al, 2002).

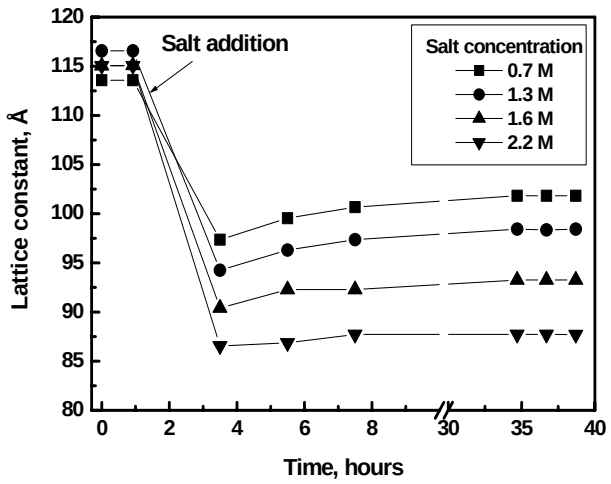


*Fig.1. The time dependence of the lattice constant of MO/BR/buffer system at different salt concentrations. The arrow shows the moment of the salt addition, which leads to significant changes of the lattice constant. The decrease of the lattice constant depends on the salt concentration.*

Thus, the presence of the macroscopic amount of an additional phase as well as a phase transition are not necessary conditions for the crystallization of BR molecules in the lipidic cubic phase. This information was one of the important steps in breaking throw the 'dogmas' of the crystallization and new approaches to the crystallization of membrane proteins have been developed (Gordeliy, unpublished). These new methods have been applied for the first time for crystallization of the complex of two membrane proteins (sensory rhodopsin II (NpSRII receptor) and transducer NpHtrII from ***Natronobacterium pharaonis***) which transfers a signal from outside to inside of the bacterial cell (Gordeliy et al., 2002).

The X-ray structure of the complex between NpSRII and the receptor binding domain of NpHtrII has been solved at 1.94 Å resolution and provides an atomic picture of the first signal transduction step (Gordeliy et al., 2002) . The sensor activate a signal transduction chain similar to that of the two-component system of eubacterial chemotaxis. The link between the photoreceptor and the following cytoplasmic signal cascade is formed by the transducer molecule which tightly and specifically binds to its cognate receptor by means of its two transmembrane helices (TM1; TM2) (Fig. 2).

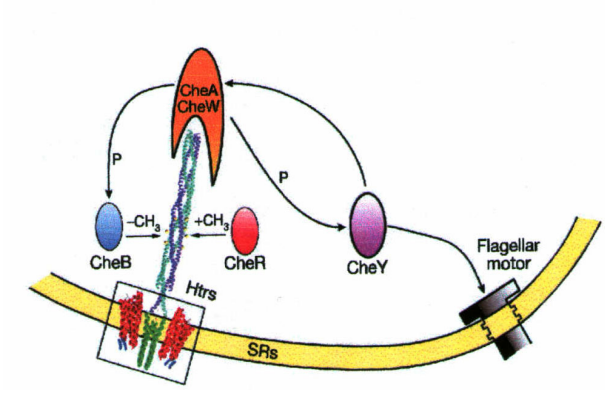


*Fig.2. Fold of the receptor/transducer complex a, Top view from the cytoplasmic side: ribbon diagram with α-helices in red for the receptor and green for the transducer, β-strands in blue, and coils in gray. The labels of the symmetry related complex are marked by an apostrophe. The crystallographic symmetry axis is located between TM1-TM2 and TM1'-TM2'. b, Side view: by B-factor mobility coloring of the structures from light red/green (less mobile) to dark red/green (mobile). ES: extracellular side; CS: cytoplasmic side.*

This work breaks new ground in several ways and is considered as a major advance in molecular cell biology of interections between proteins in a membrane embedded signal complex (Spudich, 2002). For the first time it gives the evidence for a common mechanism for signal transduction in phototaxis and chemotaxis.

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# SAXS STUDY OF TREHALOSE INFLUENCE ON THE DMPC VESICLE STRUCTURE

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## Introduction

The spatial resolution of small-angle scattering experiment mainly depends on the possibility to collect a scattering curve in the wide range of scattering vector with good enough resolution of scattering vector. Small-angle neutron (SANS) and X-ray (SAXS) scattering can be applied to study vesicles with diameter from 300 Å to 1000 Å in highly diluted systems. First efforts to investigate the internal membrane structure of unilamellar vesicles via SANS gave about 1.5 Å accuracy of the membrane thickness determination, accuracy of 2 Å of the hydrophobic core determination, and new information about membrane hydration [1]. A principal disadvantage of the SANS experiment is the incoherent scattering from hydrogen nuclei. 1% of lipid creates a background about $5 \cdot 10^{-3}$ cm$^{-1}$, which limited the maximum value of the scattering vector by 0.3 Å$^{-1}$ [1]. This limitation does not exist for SAXS. An important problem to be solved is to enhance the contrast due to the weak X-ray contrast between phospholipid bilayer and water [2]. The X-ray contrast between DMPC molecules and water is $|\Delta\rho_x| = 0.14 \cdot 10^{10}$ cm$^{-2}$. In the case of neutron scattering, the contrast is $|\Delta\rho_n| = 0.45 \cdot 10^{10}$ cm$^{-2}$, whereas the application of $D_2O$ increases the neutron contrast to $|\Delta\rho_n| = 6.34 \cdot 10^{10}$ cm$^{-2}$ [3]. 40% w/w sucrose increases the X-ray contrast by a factor of 10 compared to that of pure $H_2O$ [2,3]. The purpose of present experiment is to carried out the investigation of trehalose and sucrose influence on the structure of DMPC vesicles via precise measurements of SAXS curve in the wide range of scattering vector.

## Sample preparation and methods

20%, 30% and 40% (w/w) aqueous trehalose and sucrose solutions were used. DMPC concentrations were equal to 1% and 3% (w/w). Unilamellar DMPC vesicles were prepared via extrusion technique. SAXS spectra were collected at D24 spectrometer of DCI synchrotron ring of LURE, Orsay, France. Sample temperatures during were fixed at $10^0$C and $30^0$C. Sample to detector distances were equal to 875 mm, and 2883 mm., which allowed to collect spectra in the range of scattering vectors values from 0.006Å$^{-1}$ to 0.6Å$^{-1}$. The partway of photons was everywhere in the vacuum due to the application of sample holder with quartz capillary in the vacuum. This technique decreases the value of instrument background, that is important for the measurements of SAXS curve at large q range.

## Results and discussions

Figure 1 demonstrates SAXS spectra from DMPC vesicles in 40% trehalose solution at temperatures $10^0$C and $30^0$C. Recorded SAXS curves are sufficiently different from the SANS curves obtained for the similar samples [1].

Three peculiarities relative to SANS can be mentioned from these curves without detailed model analyses:

1. Well recorded oscillations in the end of curve at large values of scattering vector, which correspond to the form factor of lipid bilayer. It is result of about 3% resolution in scattering vector of D24 instrument for q>0.2 Å$^{-1}$.
2. Maximum value of scattering vector recorded above the value of background is 0.4 Å$^{-1}$ due to the low background from instrument and sample.

3. A different contrast variation between solution and membrane in neutron and X-ray experiment. This difference comes from differences in scattering length densities of lipid for X-ray and neutrons. In case of neutrons average scattering length densities of head group and hydrocarbon tails are approximately the same and strongly differ from average scattering length density of $D_2O$. At neutron scattering curves one can see minimum of intensity at value of q about 0.17 Å, which corresponds to scattering from lipid bilayer. Position of this minimum $q_{min}$ can give us bilayer thickness that is equal to $2\pi/q_{min} \approx 37$ Å [5]. In case of X-ray scattering, average electron density of lipid is approximately the same as average electron density of solvent ($H_2O$). But electron density of head group and hydrocarbon tails are consequently above and below that is for water. Trehalose (sucrose) increases electron density of solvent. In this case, main part of contrast is originated from the electron density difference between hydrocarbon tails and solution.

Scattering intensity from the sample under investigation (see Fig.1) has minimum at $q_{min}$ = 0.3 $Å^{-1}$ for T = $30^0$C, and at $q_{min}$ = 0.26 $Å^{-1}$ for T = $10^0$C. It describes the deviation of hydrocarbon tail length from approximately 21 Å at $30^0$C to 24 Å at $10^0$C. This difference describes well-known hydrocarbon chain melting at the main phase transition temperature $T_m = 23^0$C.

Figure 2 demonstrate SAXS curves from DMPC vesicles in the 40% trehalose and 40% sucrose aqueous solutions. These curves are approximately the same. We can conclude for very diluted vesicular population that the influence of trehalose on membrane structure is the same as the influence of sucrose.

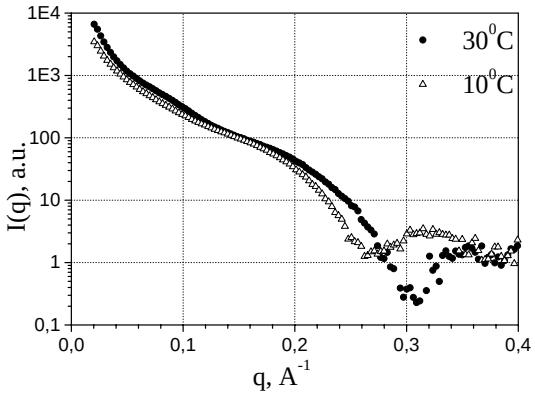


*Fig.1. SAXS curves from 500Å DMPC vesicles in 40% trehalose solution at $10^0$C and $30^0$C*

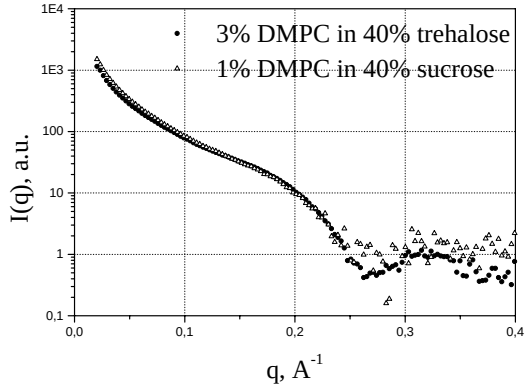


*Fig.2. SAXS curves from 500Å DMPC vesicles in 40% trehalose solution and in 40% sucrose solution at $10^0$C.*

**Conclusions**

The recorded scattering curve is good enough to be analyzed via methods developed for SANS, but with better special resolution due to large q range recoded at D24 line [4,5]. This work is in progress now. The complementary application of SANS and SAXS technique for the investigation of vesicle structure can give more detailed and precise information about internal membrane structure due to the different contrast for neutron and X-ray.

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# INVESTIGATION OF STRUCTURE OF ELONGATION FACTOR eEF-1A OF RABBIT LIVER BY NEUTRON SCATTERING AND MICROCALORIMETRY

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It is well known, that most biological functions in a cell are performed by proteins, which have a rigid three-dimensional structure. Among these proteins one can find those having locally disordered regions, which are well detected by the X-ray structure analysis and nuclear magnetic resonance. For some of these proteins a connection between the structure of disordered regions and their function was determined.

In addition, there are proteins with globally disordered structure, having a definite function. Among them are small proteins of monomeric glucagon type and proteins performing regulatory functions. Moreover, at present there is a hypothesis that practically all regulatory proteins have a globally disordered structure. The most appropriate methods to investigate the structure of such proteins are small angle neutron scattering and microcalorimetry, which give the most comprehensive description of their structure. The application of these methods to investigation of the elongation factor protein of rabbit liver (eEF-1A) gives us ground to conclude, that the investigated protein is globally unstructured and has an unfolded conformation in solution. The very structure makes it possible for one protein to interact with different ligands. We presume, that the very absence of rigid-fixed conformation in factor eEF-1A can account for its well-known ability to form complexes with different cell ligands, starting from actin and tubulin to components of the ubiquitin-dependent proteolytic system.

**Main experimental results**

Conformation of the eukaryotic elongation factor extracted from rabbit liver was studied in solution by neutron scattering and scanning microcalorimetry. It was shown, that in contrast to its bacterial analogue (EF-1A), protein eEF-1A has no fixed, rigid structure in a wide range of guanidinediphosphate (GDP) concentrations. Its dimensions in solution surpass considerably those of EF-1A. Calculated from the heat absorption curves, the value of enthalpy for eEF-1A proved to be essentially lower than that of its prokaryotic analogue EF-1A, which is indicative of partially unfolded state of the molecule. Despite the absence of rigid structure in solution, eukaryotic elongation factor eEF-1A forms a solid complex with natural ligand (t-RNA), whose stability is $10^4$ times higher than that of its prokaryotic analogue. In complex with t-RNA protein eEF-1A becomes essentially more compact.

**Conclusions**

The obtained experimental data make it possible to look in a principally new way upon some aspects of RNA-protein interactions in the process of protein biosynthesis in eukaryotic cells. Let us mention some of them.

***1. Eukaryotic factor eEF-1A has a considerably more unfolded conformation in solution than its prokaryotic analogue EF-1A***

Unlike its bacterial analogue EF-1A, protein eEF-1A extracted from rabbit liver has no fixed rigid structure in a wide range of GDP. Its dimensions in solution surpass considerably those of

EF-1A and depend essentially on GDP concentration. According to scanning microcalorimetry data, protein eEF-1A without GDP consists of two independent thermodynamic domains with transition temperatures 38 $^{o}$C and 45 $^{o}$C. In the presence of 20 мkM of GDP the second domain stabilizes: its transition temperature increases on 4 $^{o}$C. The further increase of GDP concentration leads to a greater stabilization of the protein molecule: at 20 мM of GDP the protein melts as a single peak at the transition temperature 60 $^{o}$C. Similar behavior is common for certain proteins: serum albumin, histons, some ribosomal proteins. Now it is known, that these proteins are not so compact as small globular proteins. Thus, for instance, only central part of a histon molecule is compact. According to calorimetric data, we come to the conclusion that protein EF1-A has no rigid fixed structure in the experimental conditions.

***2. Conformational changes in eukaryotic factor eEF-1A during the forming of complex with tRNA are of much larger scale than those of prokaryotic factor EF-1A during a similar complex formation.***

Despite the absence of fixed rigid structure in solution, eukaryotic elongation factor eEF-1A forms a solid complex with deacylated tRNA, the stability of which is $10^4$ times higher than that of its prokaryotic analogue. The preliminary data indicate, that protein eEF-1A becomes considerably more compact in complex with tRNA, complex appears to be one molecule of tRNA per two molecules of the protein. Our data lead to a clear conclusion, that conformational changes in factor eEF-1A occurring during a complex formation are of much larger scale than those occurring during a complex formation between EF-1A and t-RNA in prokaryotic cell. As far as we know, such large conformational changes in proteins have not been described in literature until now.

***3. Principles of functioning of the elongation factors in prokaryotic and eukaryotic systems are probably different.***

Our experimental data point at principle differences of structural bases in functioning of the elongation factors in prokaryotic and eukaryotic cells. In solution prokaryotic factor EF-1A with a high affinity to tRNA has a folded compact conformation, which changes little interacting with tRNA. On the contrary, in solution eukaryotic factor eEF1-A has an unfolded non-fixed conformation, which compactifies greatly during increasing of GDP concentration and during interacting with tRNA. This gives us reason to presume that main idea based on the coincidence of principles of functioning in elongation factors in prokaryotic and eukaryotic systems must be essentially refined.

***As a conclusion, it should be noted, that our new data demonstrate a fundamental importance of structural information obtained by small angle neutron scattering in the study of structure of globally unstructured proteins in solution and their interactions with natural ligands.***

**The paper is accepted for publication in the international scientific magazine “Biochemistry” under the title of “Conformation of the mammalian translation elongation factor 1A in solution”**

# SMALL-ANGLE NEUTRON SCATTERING STUDY OF THE BILAYER THICKNESS IN UNILAMELLAR DOPC LIPOSOMES PREPARED BY THE CHOLATE DILUTION METHOD: *N*-DECANE EFFECT

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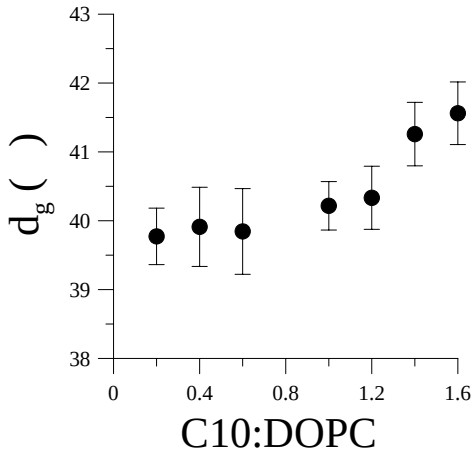
It has been observed that *n*-decane (C10) and its brominated analogs modulate the activity of sarcoplasmic reticulum Ca-Mg-ATPase reconstituted in unilamellar 1,2-diacylphosphatidylcholine liposomes by the cholate dilution method [1, 2]. Since the enzyme activity critically depends on the phosphatidylcholine acyl chain length [1-3], effects of *n*-alkanes on its activity have been ascribed to their effects on the thickness of lipid bilayer surrounding the protein [1]. The results of x-ray diffraction on the lamellar $L_\alpha$ phosphatidylcholine phase supported this conclusion – ~10 Å increase of bilayer thickness was observed in the presence of excess C10 [4]. We study the effect of C10 in unilamellar liposomes prepared by a cholate dilution method mimicking closely the enzyme reconstitution procedure.

Equimolar dioleoylphosphatidylcholine (DOPC) and sodium cholate in mixed micelles in $D_2O$ were diluted step-wise to 8 mM DOPC concentration in $D_2O$. To the liposomes thus prepared, C10 was added in methanol. After methanol evaporation, the samples were studied by SANS. From the Kratky-Porod plot $\ln[I(Q)Q^2]$ vs. $Q^2$ of SANS intensity $I(Q)$ in the range of scattering vector $Q$ values corresponding to 0.001 Å$^{-2}$≤$Q^2$≤0.006 Å$^{-2}$, the bilayer radius of gyration $R_g$ and the bilayer thickness parameter $d_g$=12$^{0.5}$$R_g$ were obtained. The values of $d_g$ indicate that the bilayer thickness is within the experimental error constant up to C10:DOPC~0.6 molar ratio, and increases then by 2.4±0.9 Å up to C10:DOPC=1.6 molar ratio (see Fig.).

The change of the DOPC bilayer thickness in unilamellar liposomes is relatively small up to *n*-decane:DOPC=1.6:1 molar ratio comparing to ~10 Å increase in the lamellar $L_\alpha$ phase. This seems to be caused by a change in the *n*-decane location when the bilayer becomes curved as in liposomes. The method of preparation and the full hydration of phospholipis in liposomes make this system to be a more appropriate model of bilayer surrounding the protein than the partially hydrated $L_\alpha$ phase. It is thus evident, that changes in Ca-Mg-ATPase activity induced by *n*-decane are not primarily caused by the changes in the bilayer thickness as originally proposed by Johansson et al. [1], but rather by the direct interaction of *n*-decane with the Ca-Mg-ATPase hydrophobic binding sites as suggested in [2, 3].




**Acknowledgements**
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# SELF-ASSEMBLY OF POLYELECTROLYTE RODS IN POLYMER GEL AND IN SOLUTION: SMALL-ANGLE NEUTRON SCATTERING STUDY

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Rigid-rod polyelectrolytes based on sulfonated poly-(p-phenylene) are able to aggregate in aqueous media due to the hydrophobic character of their backbone. This aggregation does not lead to precipitation because the charged sulfonate groups ensure the solubility of the aggregates in water. The first data on self-aggregation of sulfonated poly(p-phenylene)s in aqueous solutions were obtained by SAXS.[2] SAXS data showed that aggregated polymer chains take the form of columnar micelles, in which the phenylene backbones are oriented parallel to the axis of the micelle.[2] The magnitude of the radial aggregation number of the micelles was estimated for a series of sulfonated poly(p-phenylene) samples differing in charge density and in hydrophobicity. No information was obtained about the length of these aggregates from the evaluation of the SAXS data. It was emphasized [2] that the observed behavior of these polymers in solutions resembles the formation of supermolecular structures of some biogenic wormlike or stiff polyelectrolytes such as DNA or collagen. Therefore, a detailed study of the aggregates of rods in water could lead to better understanding of the processes of self-organization of biological macromolecules as well. On the other hand, it was shown that the ability of the macromolecules to aggregate can be used to immobilize them inside a water-swollen gel without formation of covalent bonds with the network.[3] The incorporation of rodlike polyelectrolyte in superabsor-bent hydrogels was proposed as a simple and efficient way for the improvement of mechanical properties of hydrogels in the swollen state which could be important for practical applications.[3] To control the properties of the gels with embedded rigid rods, the self-assembly of rod macromolecules inside the network should be studied. In our previous communication,[3] an indirect evidence of the self-aggregation of rods inside the gel was obtained from the results of the experiments on the swelling behavior of the gels. The aim of this work is to investigate the self-assembly of rigid-rod polyelectrolyte inside the water-swollen gel and to establish effects of the gel on the self-assembly of rods as well as of the rods on the gel structure.

**Experimental Section**

The synthesis of poly(sodium p-phenylene-sulfonate) PPP2 is described elsewhere.[3,4] Characterization of the precursor polymer which had sulfonate groups protected as 3,5-di-*tert*-butylphenolate is presented in refs 3 and 4. The degree of polymerization Pn of the precursor polymer is equal to 23.5; the contour length equals 18 nm. The persistence length of the precursor polymer was shown to be equal to 13 nm. This value can be regarded as the lower bound of the persistence length of the polyelectrolyte under study. Therefore, the PPP2 chains can be considered as rodlike chains. Polymer solutions were prepared by weighing the polymer and the solvent (D2O), mixing them and stirring at a temperature not higher than 95 °C for 20 min. For preparation of the polyacrylamide (PAAm) gels with embedded PPP2 rods, the mixture of D2O and H2O (80/20 v/v) of given composition was used as a solvent. The D2O/H2O mixture was added to 90 mg of acrylamide and to a calculated amount of PPP2 to have a resulting mass of the sample of 850 mg. Then 50 mg of 0.126 mol/L *N,N*-methylenebis(acrylamide) solution prepared in the same solvent was added, and the mixture was stirred at room temperature during at least 12 h. After the mixture was stirred, 50 mg of solution of ammonium peroxodisulfate ($4.4 \times 10^{-4}$ mol/L) and 50 mg of a solution of *N,N,N′,N′*-tetramethylethylenediamine ($4.4 \times 10^{-4}$ mol/L) prepared in

the same D2O/H2O mixture were added. The mixture was stirred again for 5 min and poured into special dismountable cell for further polymerization, which was performed over at least 24 h. D2O (99.9%) from Fluka was used as received. Water was purified with a Milli-Q system (Millipore).

## Conclusions

Self-aggregation of rigid-rod poly(sodium p-phenylenesulfonate) in aqueous solution and inside water-swollen polyacrylamide gel was studied by small-angle neutron scattering. It was shown that both inside the hydrogel and in solution polyelectrolyte rods self-assemble into cylindrical aggregates having eight to nine single polymer chains in the cross-section, the chains being aligned parallel to the axis of the aggregate. The length of these aggregates is much higher than the contour length of a single chain. Gels with embedded rods were studied by contrast variation method in order to examine separately the scattering by the gel and by the rods. Two important observations were made. First, it was shown that the ordering of the rods in the gel resembles that in solution. Second, it was shown that the gel itself is more homogeneous in the presence of rods. Most probably, this effect is due to mobile counterions of rods, which counteract the formation of spatial inhomogeneities in the network during synthesis, because in an inhomogeneous network mobile counterions should be also distributed nonuniformly that is associated with significant translational entropy losses.

A comparative study of the aggregation of polyelectrolyte rods inside a water-swollen gel and in aqueous solutions was performed by SANS. It was shown that both in solution and in the gel the polyelectrolyte rods form cylindrical aggregates consisting of ca. 9 single molecules per a cross section. It was demonstrated that the polyelectrolyte rods affect the structure of PAAm network making it more homogeneous.

## Acknowledgment

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# STRUCTURE AND POSSIBLE CLUSTER FORMATION IN LIQUID LEAD-POTASSIUM ALLOYS

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**Abstract.** The static structure factors $S(Q)$ for liquid lead and Pb-K alloys obtained by neutron diffraction are presented. The binary system was investigated for potassium concentrations of 5, 14, 22, and 25 at.% at 660 K and for the eutectic point of 9 at.% at 630 K. A weak elevation of $S(Q)$ is found in front of the main peak for the $Pb_{0.95}K_{0.05}$ and $Pb_{0.91}K_{0.09}$ alloys and a prepeak for the $Pb_{0.86}K_{0.14}$, $Pb_{0.78}K_{0.22}$, and $Pb_{0.75}K_{0.25}$ ones. This points to the formation of clusters for rising potassium concentration in liquid lead.

Alloys of lead and potassium were and remain untill now the subject of numerous macro- and microscopic investigations in a wide temperature range by neutron diffraction [1], molecular dynamics [2], and the reverse Monte Carlo method [3]. The increased interest to this systems results from Zintl clusters which possibly exist in the liquid Pb-K matrix for potassium concentration ? 25 at.% in the form of quasi-molecular group, $(Pb_4)^{4-}(K^+)_4$, in tetrahedral packing atoms. Our preliminary data for a liquid Pb-K alloy in eutectic point of 9 at.% K do not confirm such clusterisation. Therefore, close attention is needed to investigate the microstructure of the Pb-K melt for potassuim concentration ranging from 5 up to 25 at.%. The binary Pb-K system was also studied for possible correction of the properties of a lead melt as a prospective coolant for fast nuclear reactors.

These are the reasons which have induced us to carry out neutron-diffraction research of four Pb-K alloys at potassium concentrations of 5, 14, 22, and 25 at.%, as well as liquid lead for comparing with the binary system at 660 K, which is ? 15 K higher than the liquidus point for a Pb-K alloy of 25 at.% K. We also have carried out similar research of the eutectic alloy Pb-K (9 at.%) at 630 K.

## 1. Experimental

The DIN-2PI time-of-flight spectrometer [4] was used. It is located at one of the neutron beams of the IBR-2 pulsed reactor (Frank Laboratory of Neutron Physics, JINR, Dubna). The neutron momentum transfer, $Q$, of the diffraction experiments was in the range of $0.3 < Q < 22$ $E^{-1}$. The resolution, $?Q/Q$, was estimated at about 5%.

Samples of liquid metal are made as a cylindrical layer of 2 mm in thickness, 30 mm in outer diameter, and 110 mm in height. Each sample is cased in 0.15-mm thick vanadium foil to avoid coherent scattering from the container. Information for pure lead (99.99%) and Pb-K alloys was obtained in the same experimental conditions for directly comparing the data.

The measurement procedure and primary data processing were standard [5]. The background was subtracted from experimental spectra. The corrections on self-shielding the sample in the container, container, and the vanadium standard were entered; the effect of container scattering was taken into account. A special attention was given to the multiple scattering correction, which is very important in the case of the liquid lead [6]. A correction for inelastic neutron scattering was not made.

## 2. Results and discussion

Experimental plots of $S(Q)$ are shown in Fig. 1. The data for Pb-K (25 at.%) are close to known results [1]; however in this work an enhanced intensity of $S(Q)$ at the small-$Q$ region was not found by us. For the main peak of $S(Q)$, its amplitude is decreased with growth of potassium concentration in the lead melt, the half-width grows, and the position is displaced towards small $Q$. As seen in Fig. 2, at potassium concentrations of 14, 22, and 25 at.%, a prepeak at $Q$ ? 1 $E^{-1}$ is obviously visible and can be assigned to the possible existence of the Zintl clusters in the Pb-K alloy [1].

The position of the first diffraction peak and a distance between scattering centers are connected by a ratio: $R_{max} = 7.73/Q_{max}$. $Q_{max}$ ? 1.05 $E^{-1}$ from our data and, hence, we have $R_{max}$ = 7.4 $E^{-1}$. The prepeak area grows, and its half-width is decreased with the growth of the potassium concentration over the eutectic point. Both these circumstances testify that the clusterization of the Pb-K melt amplifies with growth of the K concentration.

At a concentration lower than the eutectic point, the prepeak disappears.

The differential structure factors obtained by subtraction of $S(Q)$ for lead from those for the Pb-K alloys are shown in Fig. 3. It is visible that the curves for potassium concentrations of 5, and 14 at.% differ in form from those for 22 and 25 at.%. This specifies a character of atomic structure correlation in the Pb-K melt at a potassium concentration > 14 at.%. In comparing differential curves for the main peak of $S(Q)$ and those for the prepeak, it appears that their amplitudes are changed equivalently with the growth of potassium concentration. Thus, the short order of Bernal's tetrahedral chains in liquid lead is deformed continuously and transformed into the clusters at a growing potassium concentration in the lead melt.

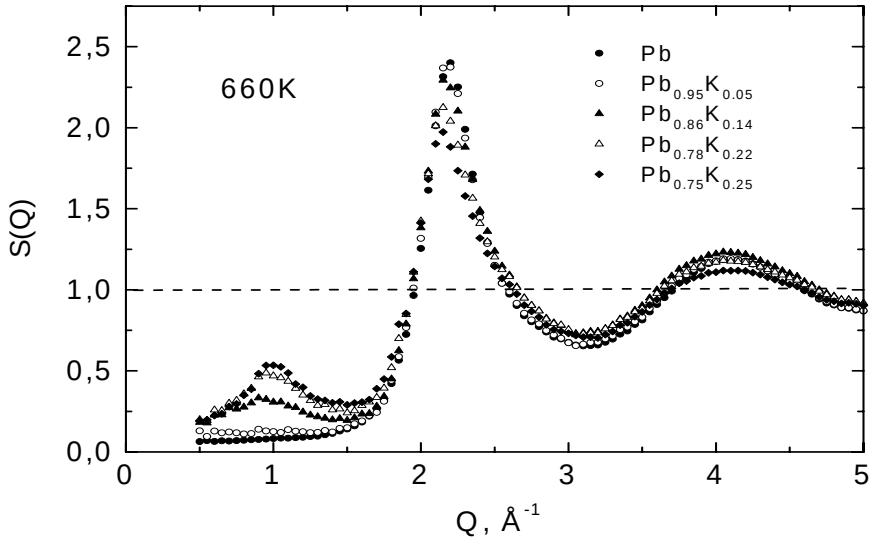


*Fig. 1. The structure factors of liquid Pb and Pb-K alloys.*

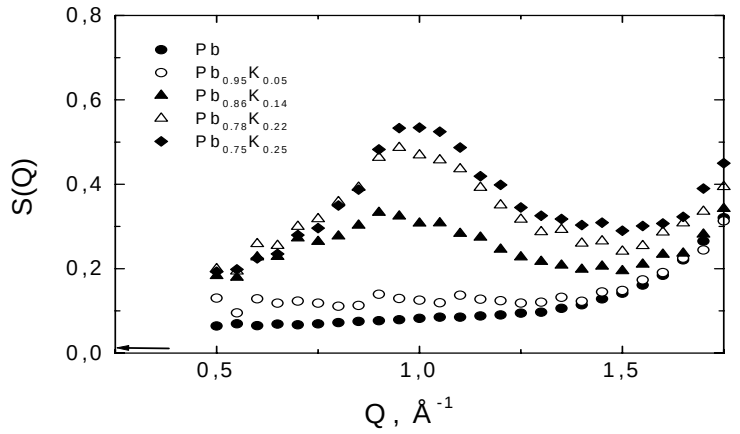


*Fig. 2. The structure factors of liquid Pb and Pb-K alloys for a small-Q region. An arrow depicts the S(0) value in a hydrodynamic limit.*

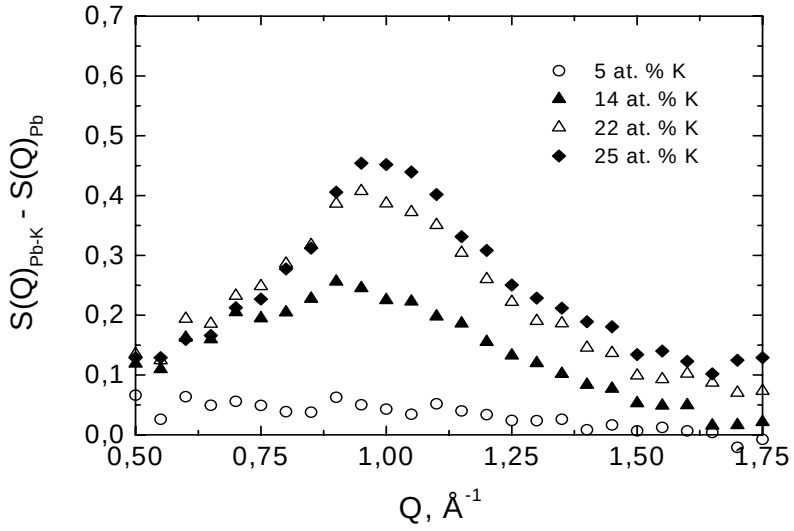


*Fig. 3. The differential structure factors for Pb-K melts in the small-Q region.*

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# STRUCTURAL PHASE TRANSITIONS AND LATTICE DYNAMICS OF SOLID MESITYLENE

I. Natkaniec

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Mesitylene or 1,3,5-trimethylbenzene - $C_6H_3(CH_3)_3$, is a well known organic solvent characterized by the relatively low freezing (227K) and high boiling (437K) temperatures. Because of high content of hydrogen and the assumed weakly hindered rotation of methyl groups in the solid phase, which can remove energy from neutrons, this compound has been recommended as neutron moderator [1], and used for construction of the TCNS cold neutrons source at the TRIGA Mark II pulsed reactor of the NETL in Austin [2]. However, the structure and dynamics of solid mesitylene until now is not well investigated.

The temperature dependence of the IINS spectra has confirmed the occurrence of rotational freedom of methyl groups in solid mesitylene at T=100K, but at T=20K the rotational jumps seems to be frozen [3]. The NDP spectra measured in this experiment for the lattice spacing up to 0.6 nm the do not indicate any diffraction peaks. As follows from the temperature dependence of the Raman spectra of $C_6H_3(CH_3)_3$, the frequencies of lattice modes and certain internal modes change at 95 and 195 K [4]. The DSC thermograms reported in [4] show two endothermic peaks for mesitylene in solid phase at 91 K and 188 K, and three endothermic peaks at 220, 222 and 227 K corresponding to the melting. This result was interpreted as manifestation of the presence of three different structural modifications Iα, Iβ and Iγ, in the high-temperature solid phase I.

Our recent simultaneous IINS and NPD investigations performed on the NERA spectrometer [5] at the IBR-2 pulsed reactor, shown up that solid mesitylen can exist in the different crystallographic structures depend on the cooling rate. At the cooling rate of 2K/min, overcooled liquid was freezing in the structure of phase II, and the first order structural phase transitions from phase II to phase III were detected at ~90 K for mesitylene-D3, and at ~100K for mesitylene-D9. Transition from phase II to phase I is not reversible, it start at approx. 190K but the NDP spectra shown pure phase I structure only after annealing of the samples at 220K. Phase I has the only one structural modification and at cooling come to be stable with respect to phases II and III. Phase II, in presence of the participation of phase I, can be also over-cooled to low temperatures [6].

Thus, three different solid phases of mesitylene can exist and may be investigated at the low temperatures. Here we present the results of the NPD and IINS investigations of solid mesitlene-D0, which were performed in order to check that solid phases obtained for partially deuterated samples can be observed as well in the hydrogenous substance [7].

The characteristic NPD spectra of the three solid phases of $C_6H_3(CH_3)_3$ recorded at T=20 K, are presented in Fig.1. The density of the phonon states and internal modes of the mesitylene molecule obtained in the range up to 300 $cm^{-1}$, on the basis of the IINS spectra for different phases of the crystalline mesitylene at T=20 K, are presented in Fig. 2. The intense bands at the frequencies 155 $cm^{-1}$and 190 $cm^{-1}$ present in the spectrum of phase III, are interpreted as corresponding to librations of the methyl groups. These bands disappear in the spectra of phases II and I, which testifies to a significant decrease of the barrier for rotation of the $CH_3$ in these phases and a shift of the libration bands into the range of lattice vibrations, below 140 $cm^{-1}$. The spectrum $G(\omega)$ for the phase II in the range of the lattice vibrations is characterised by broadened phonon bands and the so-called boson peak typical of glass phases, which corresponds to a much greater density of vibrational states in the acoustic phonon range, below 50 $cm^{-1}$. The above evidence suggests that

phase II could be classified as the proton glass. The internal vibrations of the mesitylene molecule of frequencies above 200 $cm^{-1}$ practically do not depend on the crystalline structure.

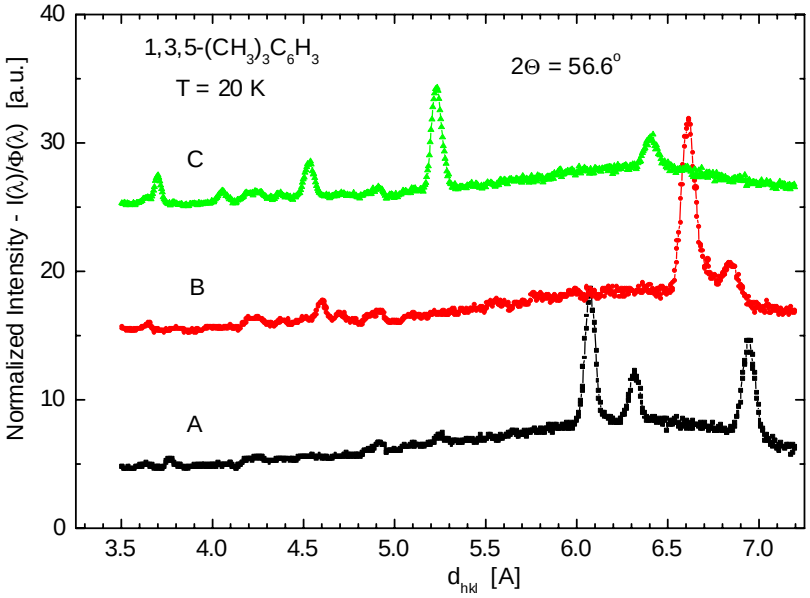


*Fig. 1. Neutron diffraction spectra recorded for $C_6H_3(CH_3)_3$ at T=20 K, A – phase III, B – phase II, C – phase I.*

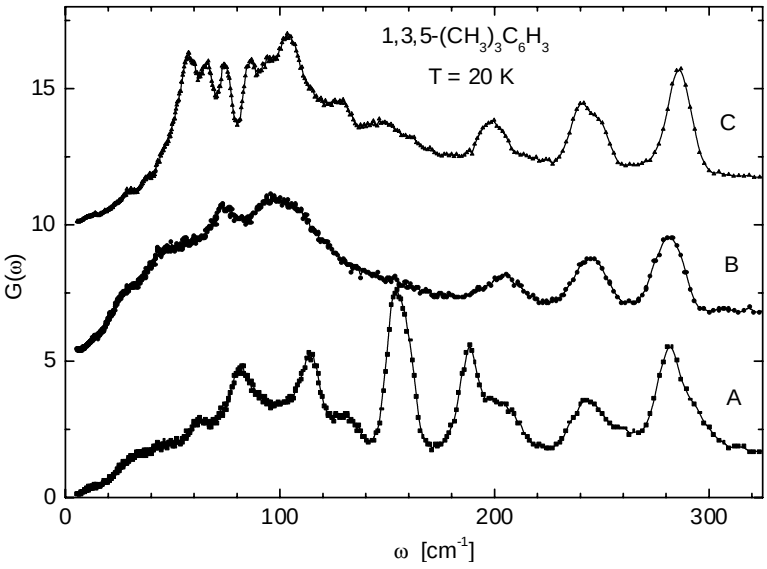


*Fig. 2. The vibrational density of states for different phases of crystalline mesitylene: A – phase III, B – phase II, C – phase I.*

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# THE INVESTIGATION OF AMMONIUM ION DYNAMICS IN $K_{1-x}(NH_4)_xBr$ MIXED CRYSTALS

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The crystal structures of KBr and $NH_4Br$ have different space groups at room temperature and form the $K_{1-x}(NH_4)_xBr$ solid solutions with limited regions near K and $NH_4^+$ [1]. KBr do not have phase transitions from room temperature to low but $NH_4Br$ undergoes the series of phase transitions [2,3]:

α-phase ⇔ 410.8K ⇔ β-phase ⇔234.9K ⇔ γ-phase ⇔ (105-78) K ⇔ δ-phase.

The cubic disordered α-phase has sp. gr. $Fm3m\text{-}O_h^5$, the cubic disordered β-phase has sp. gr. $Pm3m\text{-}O_h^1$, the ordered tetragonal γ-phase – sp. gr. $P4/nmm\text{-}D_{4h}^7$ and ordered cubic δ-phase has sp. gr. $P\text{-}43m\text{-}T_d^1$. It is worth to note that until recent time the x-T phase diagram of the $K_{1-x}(NH_4)_xBr$ mixed crystals was studied seldom.

There are presented the results of ammonium dynamics study of $K_{1-x}(NH_4)_xBr$. These investigations were carried out by the neutron powder diffraction (NPD) and the inelastic incoherent neutron scattering (IINS) on the samples with ammonium concentrations x= 0.14, 0.24, 0.52, 0.83 and 1.0 at T=23 K. These powder samples were prepared from appropriate water solutions by slow evaporation. The NPD and IINS spectra were measured on the NERA-PR spectrometer.

Concentrations x of $K_{1-x}(NH_4)_xBr$ were determined by the intensities from translational $\nu_5$ and librational $\nu_6$ modes of the IINS spectra normalized on weights and expose times. The obtained NPD spectra from $K_{1-x}(NH_4)_xBr$ were used for the determination of lattice parameters of observed α- and β-phases. It was shown that samples with x=0.14 and 0.24 are α-phase and samples with x=0.52 and 0.83 contain α- and β-phases (Fig. 1a). The dependences of the lattice parameters for $K_{1-x}(NH_4)_xBr$, at room temperature from [1] and at 23 K from recent investigation, are presented in Fig. 1b.

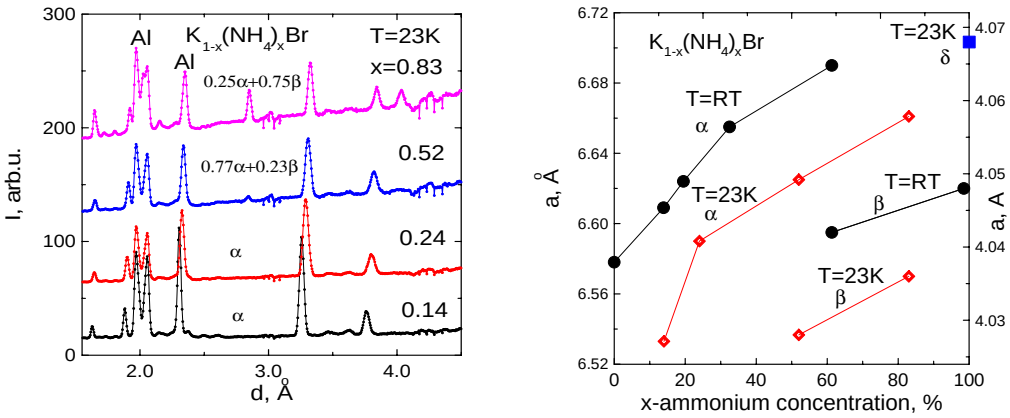


*Fig. 1. (a)-the NPD spectra of $K_{1-x}(NH_4)_xBr$ at 23 K, (b)-concentration dependence of lattice parameters for $K_{1-x}(NH_4)_xBr$ (● - data at T=RT from [1], ◘ - recent results at T=23 K).*

The obtained IINS and calculated G(E) spectra for $K_{1-x}(NH_4)_xBr$ are presented in Figs. 2(a) and 2(b) respectively. The IINS and G(E) spectra of samples with x=0.14 and 0.24 are suit to α-phase and that of samples with x=0.52 and 0.83 are suit to α- and β-phases.

The IINS spectra of the samples with x=0.14 and 0.24 show the contributions of the quasielastic incoherent neutron scattering (QINS) which is diminish with increasing of ammonium

concentration. Such behaviour can be explained as due to the orientational glass state. The G(E) spectra gives the possibility to determine the changes in $K_{1-x}(NH_4)_xBr$ with ammonium concentration. There are selected resonance modes $E_r^1$ and $E_r^2$, local translational mode $\nu_5$ and librational mode $\nu_6$ in α-phase (x=0.14 and 0.24) and only local translational mode $\nu_5$ and librational mode $\nu_6$ in β-phase (x=0.52 and 0.83). It is worth to note the splitting of librational mode $\nu_6$ in β-phase on two sub-bands. Other interest peculiarity of the G(E) spectrum of $K_{0.17}(NH_4)_{0.83}Br$ is the appearance of $\nu_5+\nu_6$ Raman mode and $2\nu_6$ second harmonic in β-phase. The G(E) spectrum of $NH_4Br$ at 23 K is suit to crystal structure of δ-phase. Concentration dependence of energies for observed modes in α- and β-phases of $K_{1-x}(NH_4)_xBr$ s presenter in Fig. 3.

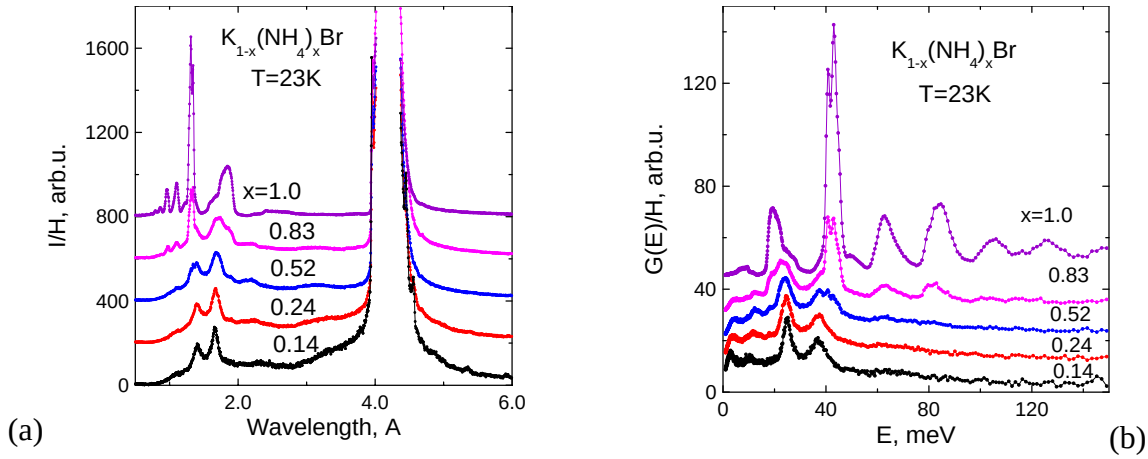


*Fig. 2(a)-the IINS spectra of $K_{1-x}(NH_4)_xBr$ at 23 K, Fig.2(b)-the G(E) spectra of $K_{1-x}(NH_4)_xBr$ at 23 K.*

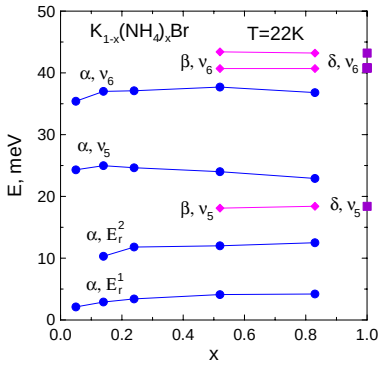


*Fig. 3. The energies of modes in different phases of the $K_{1-x}(NH_4)_xBr$ mixed crystals.*

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# NEW COMPOSITE MATERIALS: MAGNETIC NANOPARTICLES IN COPOLYMER FILMS BY SPECULAR AND OFF-SPECULAR NEUTRON SCATTERING

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We performed the detailed studies of the new composite lamellar films with a high concentration of the nanoparticles. It is shown that the polystyrene - polymethylmethacrylate P(S-b-MMAd) copolymer multilayer orders the assembly of PS-coated $Fe_3O_4$ nanoparticles into a lamellar array along the PS layers of the host matrix. The application of neutron specular reflection and off-specular scattering accompanied by a two-dimensional data analysis allows for a detailed description of the nanoparticles distribution inside the copolymer matrix. As a result, the parameters of the transverse and the lateral structure for pure of the incorporated magnetite $Fe_3O_4$ nanoparticles with the average diameter of 10 nm were obtained.

Diblock-copolymers, dissolved in toluene, cast and spin-coated onto silicon substrate. Self-assembly of the copolymer matrix is determined by the non-miscibility of the two chemical components. The lamellae are parallel to the substrate and the surface of the film and their thickness is given by nL/2 with n integer even and L the lamellar period (PMMA-PS-PS-PMMA). By coating the nanoparticles with one or another type of the polymer chains (prior to the adding to a toluene solution of the copolymer) we provide a control on the nanoparticle distribution within one or another part of lamellar structure.

We succeeded to incorporate $Fe_3O_4$ nanoparticles with the average diameter of 10 nm up to 8% of the volume fraction. Even for a high concentration particles stay included in the film and the lamellar structure is not destroyed. Periodic location of the particles as well as the transverse and lateral structure of the lamellar pure copolymer and composite films was determined using neutron specular reflection and off-specular scattering.

The presence of the nanoparticles induces distortion of the copolymer matrix. The neutron off-specular scattering contains valuable information about the internal structure of the film, including the nanoparticles' distribution, lateral structure of the roughness and its conformity through the lamellar multilayer and also the surface structure of the film.

Earlier developed theoretical approach based on the Distorted Wave Born Approximation (DWBA) allows for a description of a full 2-dimensional intensity map, including the dynamical range close to the total reflection region [1, 2].

The experiments on neutron specular reflection and off-specular scattering were performed on the REMUR reflectometer, using the time-of-flight method with the wavelength band $\lambda$ from 1 to 12 Å and the fixed scattering angle a = 0.014 rad. The data were recorded with a position sensitive detector in a wide range of incoming and outgoing wavevectors $p_i$ and $p_f$. The reflected and scattered intensities are depicted in Figure as functions of $(p_i + p_f) = Q_z$ and $(p_i - p_f)$ for two samples without (a) and with (d) nanoparticles. The specular reflectivity runs along the line $p_i - p_f = 0$ and shows regular oscillations, which are determined by the total thickness of the film. The off-specular intensity in a form of the Yoneda scattering spreads out left and right from the specular intensity line indicating the presence of the surface and the substrate roughness.The multilayer structure formed by the lamellae oriented parallel to the film surface causes the appearance of the Bragg peaks on the reflectivity line. The presence of the Bragg peaks for the sample with incorporated nanoparticles (Figure d) proves that the multilayer structure persists and is not

destroyed by a rather high concentration of the nanoparticles. However, the positions of the Bragg peaks are shifted towards smaller values of $Q_z$, indicating the increase of the lamellar period due to the presence of the nanoparticles. The off-specular intensity crossing the specular line in the Bragg peak position (so called Bragg sheets [2-4]) is due to the interfacial roughness. This intensity appears when the roughness is correlated not only within each interface but also at different interfaces across the film. The degree of this conformity regulates the ratio between the intensity of the Bragg sheet and the Yoneda scattering. The off-specularly scattered intensity from the sample with nanoparticles does not change considerably, that proves a certain degree of conformity of the interfacial roughness.

The two – dimensional fit to the experimental data was performed using the model described in details earlier [1-4] and the results will be published elsewhere[5].

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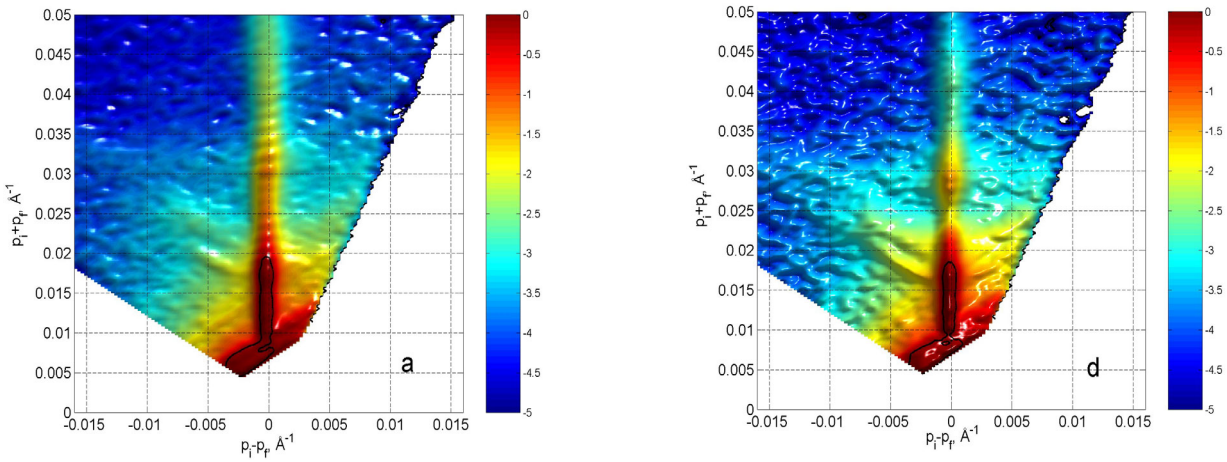


Figure. Experimental 2-dimensional intensity map from annealed samples of pure P(S-b-MMAd) thin film (a) and similar copolymer film with incorporated $Fe_3O_4$ nanoparticles (d); $p_i$ and $p_f$ are the perpendicular to the surface components of the incoming and outgoing neutron wave vectors, respectively. The strong intensity along the line ($p_i$ - $p_f$) = 0 corresponds to the specular reflection, the Yoneda scattering intensity spreads left and right from the specular line.

# EXPERIMENTAL OBSERVATION OF THE UCN FOCUSING IN TIME

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In the recent paper [1] the attention was drawn to the circumstances that by the action at a neutron wave with any nonstationary device it is possible to change neutron velocity in such a way, that conditions of neutron focusing in time would be satisfactory. In particular, the possibility of using the effect of neutron energy quantization at neutron diffraction by the moving grating for the construction of "time lens" was discussed. Recently this effect was observed experimentally [3,4]. Concluding the paper [4] we wrote: "The idea of neutron time-focusing, as proposed in [1], now looks more realistic". At the moment we can report about the first experimental observation of the neutron time focusing using nonstationary action at the neutron wave.

Figure 1 illustrates the idea of the experiment. Let monochromatic neutrons be moving along the X axis. A device, time lens, capable of changing the neutron energy follows the defined $\Delta E(t)$ dependence, which is positioned at the point x=a. As a result, the neutrons, which leave the source during some period T, reach the point of observation located at L simultaneously.

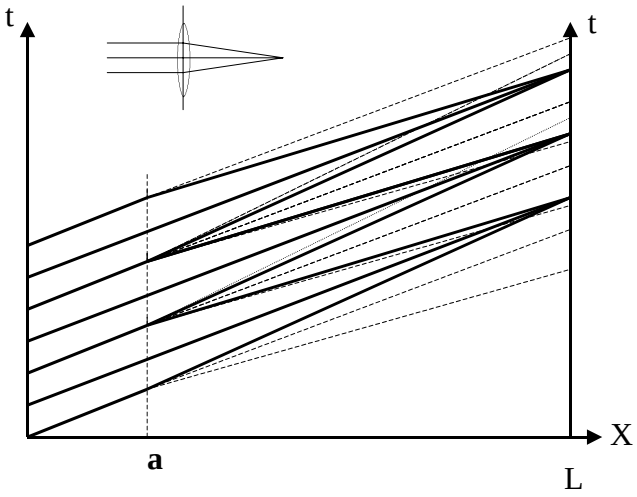


*Fig .1. The time – space diagram of the experiment*

In our experiment the active action at the neutron energy was due to diffraction of the rotating grating. The experimental set up, the modified spectrometer [5], was used in the time-of-flight mode. The neutron interference filter (NIF) was used for the monochromatization of ultracold neutrons (UCN). Only the UCNs with a narrow spectrum of vertical velocities i.e., a maximum of 4.52 m/s and FWHM of about 0.085 m/s, passed through the monochromator and reached the grating just below it. Using a motor, the grating could be spinned about the vertical axis at 6000 rpm. The vertical neutron guide with glass mirror walls transported the UCN to the neutron thin-layer scintillation detector. The $(n,\alpha)$ reaction at the $Li^6$ isotope was used for the conversion of neutrons to the charged particles. The monochromator – detector distance, i.e. the flight path, was 70 cm.

The grating was manufactured on the surface of a silicon disk, 150 mm in diameter and 0.6 mm thick. radial grooves were made by the lithographic technique in its peripheral region. The depth of grooves was 0.14 microns, which corresponded to the phase shift of $\pi$ at neutron refraction in silicon. The distance $\alpha$ between the grooves was a function of the azimuth at the grating surface. When the grating was spinning, UCNs passed through the part of it with the space period $\alpha$ and the space frequency $\alpha^{-1}$, respectively. As a result, the transmitted waves were modulated with the frequency $\boldsymbol{\Omega = 2\pi V\alpha^{-1}}$, where V is the grating linear velocity (see fig.3). So the modulation frequency $\Omega$ was variable at the constant spinning frequency.

After passing the grating, which acted as a phase modulator, the transmitted state was the nonstationary superposition of waves, each of which had the energy of $\hbar\boldsymbol{\omega_n}$ and corresponded to the wave number $\mathbf{k_n}$

$$\Psi(x,t) = \sum_{n=-\infty}^{\infty} c_n e^{i(k_n x - \omega_n t)}, \text{ with } \omega_n = \omega_0 + n\Omega, \; k_n = k_0(1 + n\frac{\gamma}{2}), \qquad (1)$$

In the case under consideration, the phase $\pi$ -modulation, the coefficients of $c_n$ in eq.(1) are

$$c_n = \frac{2}{i\pi n}, \quad n = 2s - 1. \qquad (2)$$ It is follows from eq.(2) that the waves of the even order including the zero one, which corresponds to the wave with initial energy, were absent in the final state, Only the wave of the first order ( with n = –1 during the half of the rotation period and n = +1 during other time) were focused. All other waves were a source of the background. In accordance with eq. (2) the limited possible efficiency of such lens is $|c_1|^2 \approx 0.4$.

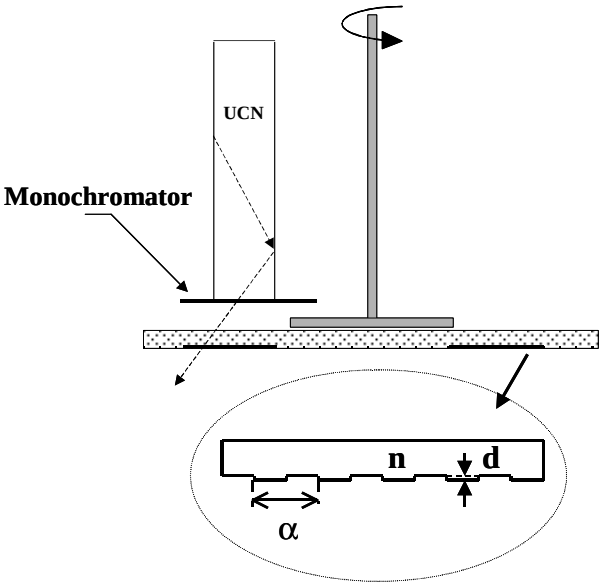


*Fig.2. Principle of the experiment. When the grating is spinning, each point of the monochromatic UCN beam is crossed by the moving grating*

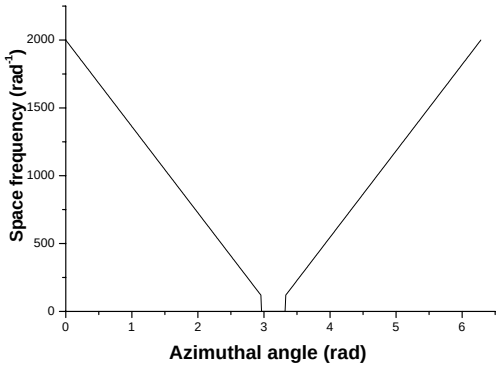


*Fig.3. Dependence of the grating space frequency on the azimuth angle at the grating surface*

In figure 4 the time-of-flight spectrum obtained in the experiment with rotating grating is represented. The time scale is equal to the rotation period. Rotation frequency is 5820 rpm. It is seen clearly in this figure that moments of the neutron rich detector are not distributed arbitrary but are grouped around some value. Note that the neutron time of flight is about 140 msec, which is 14 time larger than the rotation period.

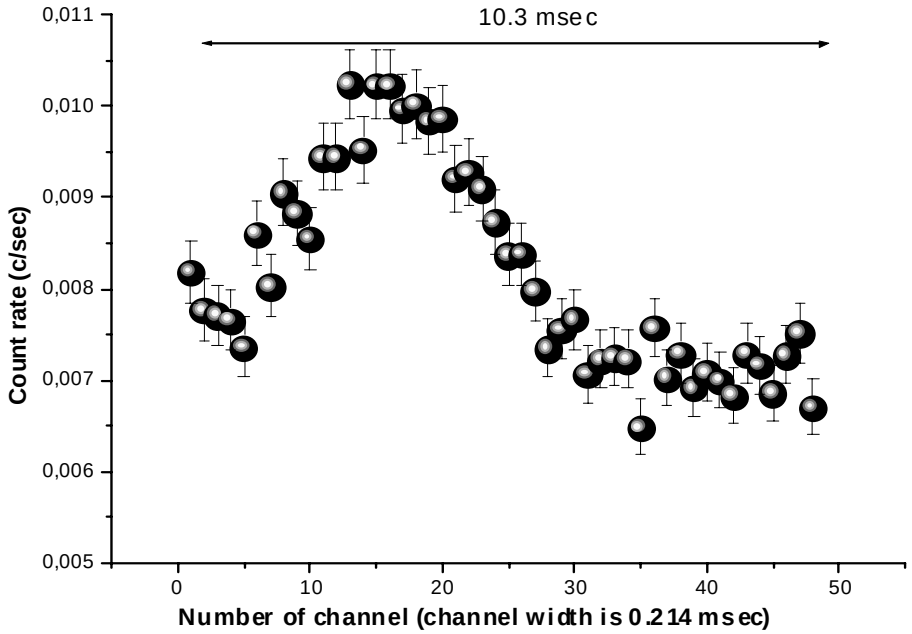


*Fig. 4. Time focusing effect*

The measurements were done at a number of different rotation frequencies. When the frequency decreases the time scale is also deformed and the visible position of the focusing peak shifts at this scale, respectively. At the same time the width of the peak increases and when the frequency becomes about 2000rpm the focusing effect disappears.

The focusing efficiency was around 17% while it limit value is 40%. Similar intensity of the first order waves was detected earlier in [3,4]. Probably, this deficit in the value of efficiency is due to the quality of grating used in the last experiment, which was not good enough.

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# THE REASON FOR SMALL CHANGES IN ENERGY OF ULTRACOLD NEUTRONS (UCN) IN TRAPS

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The nature of the phenomenon of small changes in energy of ultracold neutrons (UCN) is investigated. This phenomenon consists in the increasing of UCN energy (heating) by ~$10^{-7}$eV with the probability of $10^{-8}$-$10^{-5}$ per collision with a surface. Such neutrons are named VUCN (vaporized UCN). We found that preliminary outgasing of samples at 500-600 K leads to increasing of the "small heating" probability at least 100 times on a surface of stainless steel and ~10 times on a copper surface. Extremely intensive UCN "small heating" by diamond nanoparticles powder have been observed for the first time. The spectrum of neutrons heated on nanoparticles powder and the temperature dependence of the heating probability are similar to those observed for stainless steel, beryllium and copper. We have observed neither small UCN heating, nor nanoparticles on a mono-crystalline sapphire surface. Thereby the phenomenon of "small heating" can be related to inelastic scattering of UCN by thermal motion of nanoparticles weakly bound to surface.

In 1997, we found an additional channel of losses of ultracold neutrons (UCN) from traps [1]. These losses are due to increase in energy of UCN by ~$10^{-7}$eV with the probability of $10^{-8}$-$10^{-5}$ per collision with surface. If the energy of a neutron after this inelastic scattering exceeds a certain critical value, it leaves the trap. This process is similar to "vaporization" of UCN from trap (see Fig.1). For this reason, such neutrons are named "vaporized" UCN (VUCN).

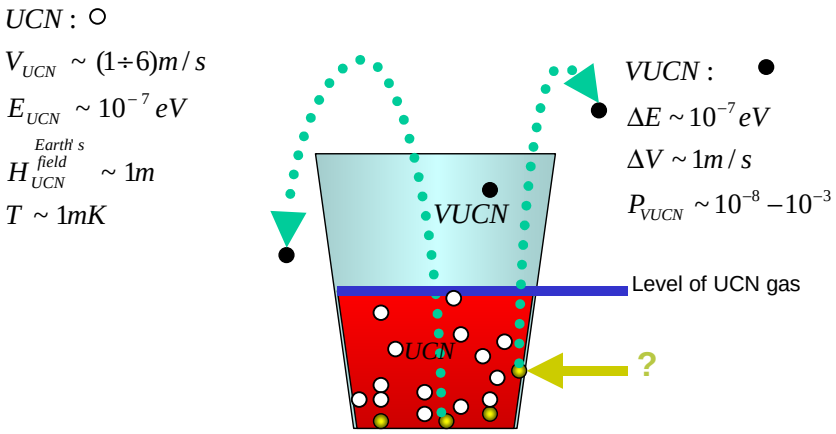


*Fig.1 Illustration of losses of UCN from a trap via VUCN production. The typical parameters of UCN (velocity, energy, rising height in the gravitational field, temperature) and VUCN production (change in energy, in velocity, the probability) are shown on the picture.*

In order to investigate the nature and characteristics of this phenomenon, we constructed a big gravitational spectrometer (BGS) (see Fig.2).

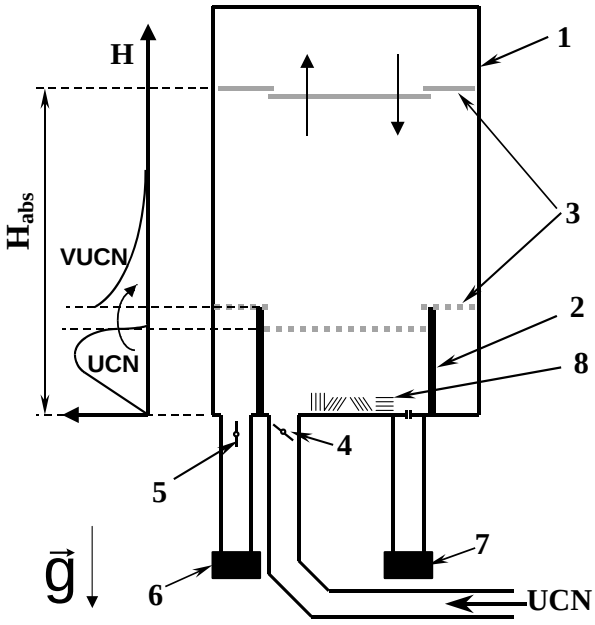


*Fig.2 Scheme of the gravitational spectrometer.*
*1 – evacuated volume; 2 – gravitation barrier;*
*3 – absorber in upper (solid line) and bottom (dashed line) position ;*
*4 – input valve; 5 – output valve; 6 – detector; 7 – monitor.*

This spectrometer can simultaneously detect stored UCN and formed VUCN. Contrary to previous setups, the BGS provides detection of VUCN in a broader energy range (50-150 neV) and with higher efficiency (~50%). This efficiency is measured rather than estimated over the entire energy range in order to ensure the accuracy and reliability of results. The spectrometer was designed so that samples can be rapidly and conveniently replaced, and the setup can be adapted for various experimental problems. The spectrometer volume hermetically separated from the vacuum enclosure can be heated up to 600 K or cooled down to 80 K. The spectrometer is described in ref. [2]. Fig.3 shows the typical time dependence of the detector count rate with various samples. During filling the spectrometer ($0^{th}$-$100^{th}$ s), neutrons with energies higher than the gravitational barrier can penetrate into the detector. After closing the input valve ($100^{th}$ s), these neutrons are rapidly absorbed, and the detector count rate falls down for a short time. Then at $170^{th}$ s, after cleaning the spectrum from above-barrier neutrons, the absorber is lifted up and allows in this position to measure VUCN – neutrons which have changed their energy due to interaction with surface of samples placed in the spectrometer and with the spectrometer walls. The detector count rate rises and, after a certain time, becomes proportional to the flux density of UCN closed by the gravitational barrier in the spectrometer. At the $590^{th}$ s, the absorber is drawn down**,** and the detector count rate falls down to the background value.

The probability of the small heating of UCN interacting with metal surface (stainless steel, copper) was measured with a higher accuracy by a more reliable method than in previous experiments [1,3,4]. The new measurement confirms our previous results obtained with similar samples for both the probability of this process and for the shape of the integral VUCN spectrum. For the first time, the integral VUCN spectrum was measured with accuracy sufficient for calculating the differential spectrum.

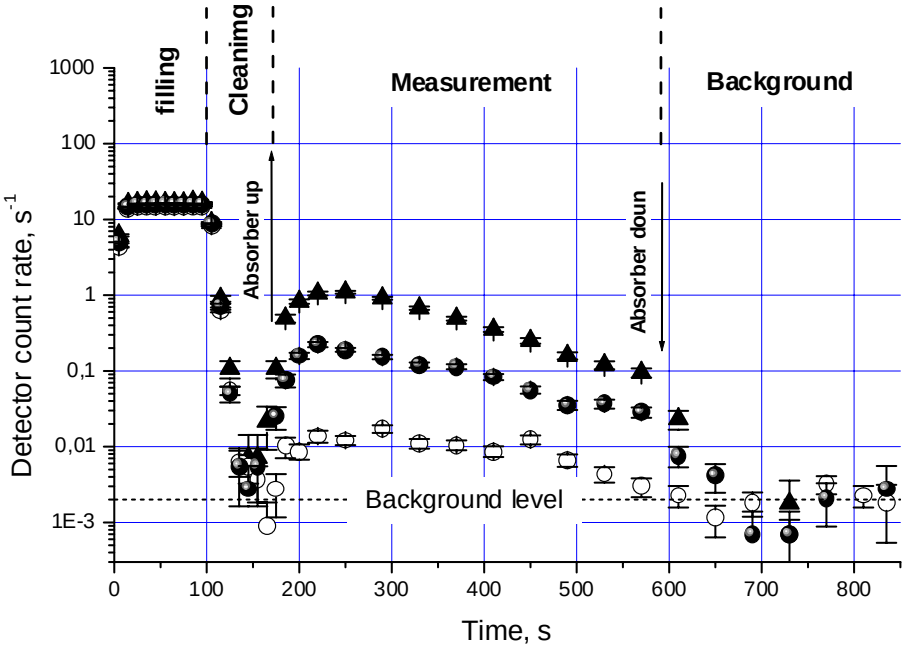


*Fig.3. Detector count rates for different samples: measurements (○) on surface of empty copper spectrometer, (●) with stainless steel samples, and (Δ) with diamond nanoparticles powder. The dashed line shows the background level.*

We have established that the probability of small heating of UCN depends on the procedure of preparing the stainless steel samples. Indeed, a preliminary heating of sample at the temperature of 500-600 K increases the probability of small heating of UCN by a factor of ~100! The independent measurements with identical samples indicate that this result is well reproducible (see Fig.4). Measurements with an atomic-force microscope showed a big increase in population of nanoparticles at the surface just at this "peak" temperature. The similar abrupt increase in the probability of small heating (by a factor of ~10) after heat treatment was also observed for the interaction of UCN with a copper surface. It should be noted that the preliminary heating of surfaces of traps and samples up to these temperatures is the routine preparatory procedure in UCN storage experiments. Therefore the interpretation of experiments where UCN losses caused by small heating are not explicitly measured is unreliable.

We consider the acceleration of UCN by the thermal motion of solid nanoparticles weakly bound to a surface as the most probable cause of the small heating of UCN [5]. In order to verify this hypothesis, we deposited a powder (~1cm$^3$) of diamond nanoparticles with a mean size of ~5 nm (Ultradiamond-90) on an area of ~150cm$^2$ on the copper bottom surface of the spectrometer. In this case, the VUCN flux increased strongly (see Fig.3), and the probability of VUCN production reduced to this area was as high as ~$10^{-3}$ per collision. The VUCN spectra measured in this study and in [1,3,4] on the stainless steel surface coincide with the spectrum measured on the nanoparticles-powder surface. The temperature dependence of small-heating probability measured in the range of 100-300 K for the diamond-nanoparticle powder coincides with the dependencies measured in [3] for the beryllium and copper surfaces. Furthermore, the VUCN spectrum does not significantly depend on temperature in the temperature range 100-300 K.

Whereas we observed a high VUCN flux from the nanoparticles powder, small heating of UCN on the surface of a sapphire single crystal was not detected. The probability of this heating was measured to be $(0.0\pm1.2)\cdot10^{-8}$ per collision. In this case, the scanning atomic force microscope observed no nanoparticles on this surface.

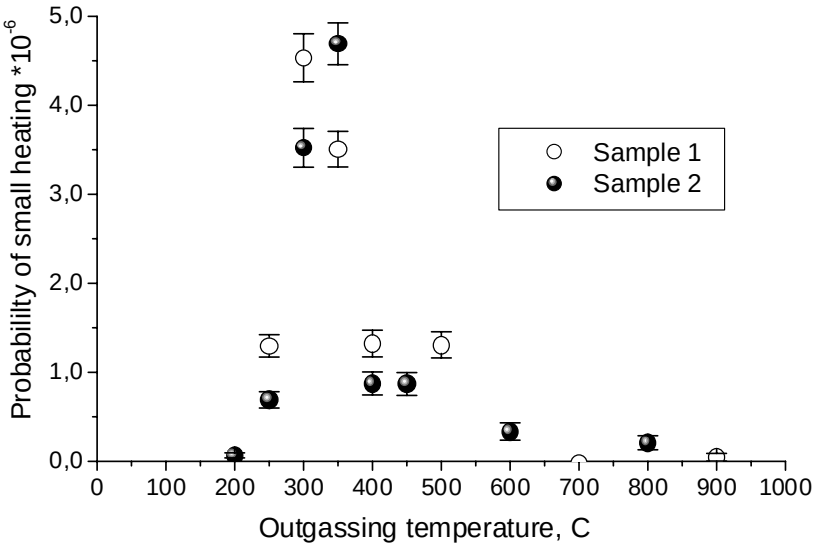


*Fig.4. Probability of the small heating of UCN as a function of the outgassing temperature for two stainless steel samples.*

The results of this study indicate that the small heating of UCN interacting with a surface is caused by their acceleration in collisions with very small solid particles that are weakly bound to surface and are in permanent thermal motion.

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# RECENT RESULTS ON THE MEASUREMENTS OF THE P-ODD CORRELATIONS IN THE CAPTURE OF SLOW POLARIZED NEUTRONS BY $^{6}$Li AND $^{10}$B

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One of the basic predictions of a standard model of the electroweak interaction is the existence of neutral currents. These currents were observed without any ambiguities in the leptonic and semyleptonic processes. However till now the weak neutral current in the NN-interaction is not found out. The major circumstance determining prospects of studying of the P-odd effects in NN-interaction is the possibility of its theoretical interpretation in terms of constants of the NN-potential breaking parity and the nuclear matrix elements which are included in expression of observable P-odd values. The promising direction for the exploration of the properties of neutral currents in the weak NN-processes is the reactions of slow polarized neutrons with light nuclei (A=6-10). These nuclei are well described in cluster and multycluster schemes. Then the task of calculation of the P-odd effects can be solved, using methods, applied for fewnucleon systems. Within the framework of such approach in Ref [1, 2], the P-odd correlations of the triton emission in the $^{6}$Li(n,$\alpha$)$^{3}$H reaction and the $\gamma$-quanta emission at transition from the first excited state of $^{7}$Li*$\rightarrow^{7}$Li+$\gamma$(M1), $E_\gamma$=0.478 MeV, populated in the $^{10}$B(n,$\alpha$)$^{7}$Li reaction with polarized thermal neutrons, were expressed in terms of weak meson exchange constants. Estimations show, that the possible contribution of neutral currents to the asymmetry values is about 30-50 %. Thus, having measured P-odd correlations and using the values of constants for the charged currents confirmed with experiment, it is possible to obtain an estimation on the contribution of neutral currents to NN-interactions. Expected values of the P-odd correlations are small - $\alpha^{t}_{PNC}\sim 3\cdot 10^{-7}$, $\alpha^{\gamma}_{PNC}\sim 5\cdot 10^{-8}$, however, the high cross sections of the mentioned reactions with thermal neutrons give the possibility to get the P-odd asymmetry with an accuracy of $\sim 10^{-8}$.

The experiments on research of the P-odd asymmetry in the $^{6}$Li(n,$\alpha$)$^{3}$H and $^{10}$B(n,$\alpha$)$^{7}$Li*$\rightarrow\gamma\rightarrow^{7}$Li(g.s.) reactions were carried out at the PF1B instrument of the ILL reactor, Grenoble, France. The mean wavelength of the neutron spectrum was $<\lambda_n>$= 4.7 Å. A focusing supermirror polarizer sized the beam of 100 mm in height and 50 mm in width at a focal length (1.8 m). An integral polarized neutron flux was $F_n\sim(3\text{-}5)\cdot 10^{10}$ s$^{-1}$. The degree of polarization was $P$=(94±2)%.

The scheme of the experimental setup for the investigation of the $^{6}$Li(n,$\alpha$)$^{3}$H reaction is represented in fig. 2. The longitudinally polarized neutron beam was used. A geometry of experiment was $\vec{\sigma}_n \| \vec{p}_n \| \vec{p}_t$. To registration of tritons a 48 section ionization chamber was applied. 24 lithium targets were placed along the chamber. The plane of targets was installed

perpendicularly to the beam axis. The targets were the $^6$LiF layers of 400 μg/cm$^2$ in thickness, which were prepared by the vacuum evaporation onto the 14 μm Al-backings. In order to absorb the α-particles and to create the needed solid angle for the triton emission, each target from the side of lithium layer was covered additionally also with the 14 μm Al-foil. Each target was common for the "forward" and "backward" detecting sections. As a working gas, argon was used at pressure $p$ = 2.4 atm. The neutron beam was completely stacked in the target area. The targets utilized approximately 60% of the beam intensity. The chamber was supplied with a system of the coils to create needed permanent neutron spin guide magnetic fields. For more details see [3, 4]. The asymmetry coefficient $\alpha^t_{PNC}$ was determined as a relative difference of triton yields along and opposite the neutron spin. For it, the neutron polarization was periodically reversed with the help of a radiofrequency spin-flipper. The signal electrodes of all the "forward" and "backward" sections were connected to the common busbar "forward" and, respectively "backward" to work on two detector channels. The load on the detector was more than $10^9$ s$^{-1}$, due to it the current method of event detection was used. Electronics for the integral measurements are described elsewhere [5]. In order to awoid the possible influence of apparatus instability, neutron flux fluctuations, radiotechnical noises and false effects, the special measurement procedure was used including compensation of the reactor power fluctuations at subtraction of the "forward" and "backward" effects, and the periodical reverse of the guide magnetic field in the chamber [3-6].

In main run for 18 days the P-odd asymmetry was obtained: $\alpha^t_{PNC}$ = -(7.1 ± 3.9)·10$^{-8}$. In order to estimate the left-right asymmetry contribution, a run was performed, when a guide field was oriented perpendicularly to the neutron beam axes. It was found out that in geometry of the main experiment the contribution of the left-right asymmetry to P-odd effect does not exceed 8·10$^{-9}$. Beside of this, the background asymmetry measurement was performed without the neutron beam. It allows one to estimate possible influence of the power net noises as well as the scattering electromagnetic fields from the other working facilities in the experimental hall. The result of the background experiment is $\alpha_{BG}$ = (5.6 ± 4.3) 10$^{-9}$. The "zero" experiment with total absorption of tritium component was not done due to lack of the beam time. However, the background effect is expected to be no more than in the previous experiment [7] - $\alpha_0$ = (2.1 ± 1.7)·10$^{-8}$ (see discussion in [3, 4]).

Using the obtained value and results of the previous experiment in Gatchina [7] it is possible to estimate a meson exchange constant of the weak neutral current. A sum of the P-odd coefficients of the present experiment and [7] (weighted averaged) gives $\alpha^t_{PNC}$ = -(7.1 ± 3.3)·10$^{-8}$. Assuming, that the charged current constant is known exactly $h_\rho$ = -11.4·10$^{-7}$, and using expression from [1] we obtain $f_\pi \le 1.2\cdot10^{-7}$ at the 90% confidential level. At present, this estimation of the neutral current constant is the most accurate among others.

First experiment on the measurement of the P-odd correlation in the $^{10}$B(n,α)$^7$Li*→γ→$^7$Li(g.s.) reaction was performed in 2001 [8]. The main run gave the asymmetry coefficient $\alpha$ = + (8.8±4.6)·10$^{-8}$. The "zero"-experiments showed a significant background effect with the sign opposite to the sign of the main run value: $\alpha_0$ = -(14.8±3.3)·10$^{-8}$. In the experiment of 2002 essential part of efforts was concentrated on understanding of the nature of background effect. Number of runs were carried out to investigate construction materials of the facility and the samples. It has been established, that the sample, used in first experiment for the 0-measurements, was locally contaminated, probably, with chlorine, that gave big background effect. The main results of recent experiment are as follow: the $^{10}$B run - $\alpha$ = -(11.0 ± 6.6)·10$^{-8}$, the 0-experiment - - $\alpha_0$ = (0.7 ± 3.7)·10$^{-8}$. From the comparison wit theoretical calculation ($\alpha^{theor}$ = -7.24·10$^{-8}$) it is seen, that experimental accuracy still is not enough to make the estimation of the neutral current contribution.

At present, the feather measurements are in the stage of planning. Use of new improved polarizer gives the real possibility to increase experimental accuracy in factor of 2-3 and to get the P-odd effect values with uncertainty of ~1-1.5·10$^{-8}$.

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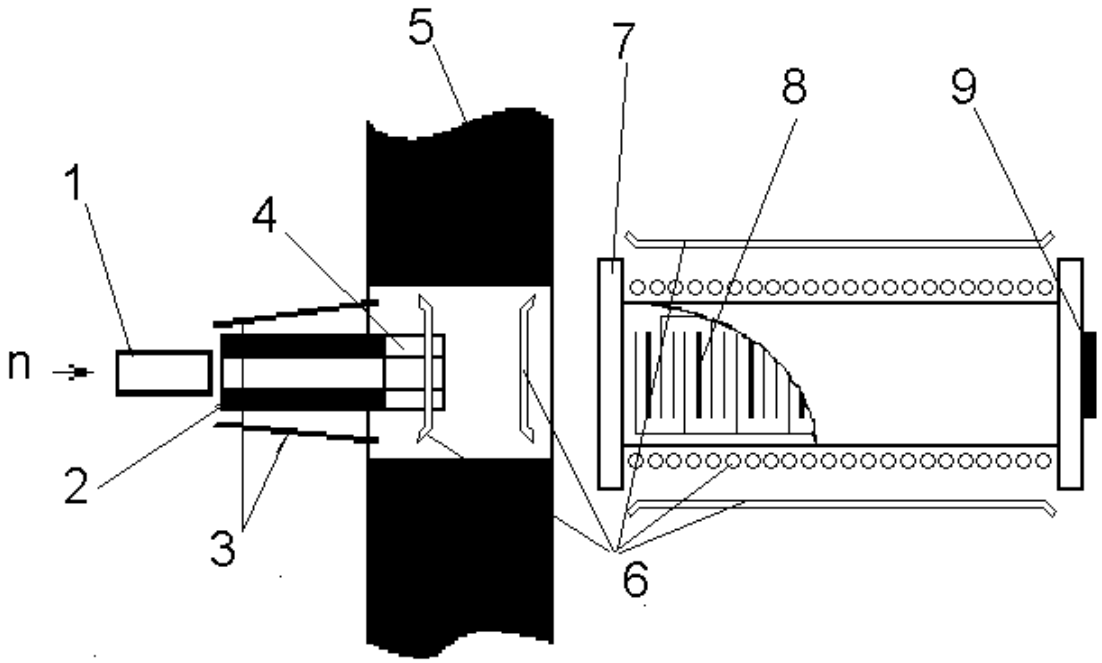


*Fig. 1. The experimental layout for the $^{6}$Li mesurements: 1- polarizer; 2- adiabatic RF spin-flipper; 3- magnetized plates of the neutron spin guide field; 4- lead collimator; 5- concrete wall; 6- coils of the neutron spin guide field; 7- ionization chamber; 8- targets and electrodes; 9- Li beam-stop.*

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# ON THE RELIABILITY OF THE MODEL-INDEPENDENT EXTRACTION RESULTS OF THE LEVEL DENSITY AND RADIATIVE STRENGTH FUNCTIONS FROM THE *(N, 2γ)* REACTION

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Until recently level density (LD) $p = D^{-1}$ and radiative strength function (RSF) $k = \Gamma_{\lambda i} /(E^3_\gamma \times A^{2/3} \times D_\lambda)$ E1- or M1-transition with the energy $E_\gamma$ and mean width $\Gamma_{\lambda i}$, connecting $\lambda$ and *i* states in the excitation range from $E_{воз} \cong$ 1- 2 MeV to the neutron binding energy $B_n$ in the nucleus with mass A were derived only from evaporative spectra of the (p, n) reaction type and primary γ-transition spectra, respectively. The main shortage of the mentioned methods is the necessity to use purely model notions about the penetration of the nucleus surface for evaporative nucleons [1] or level density in determination of RSF [2].

The situation changed when authors [3] showed that total radiative width $\Gamma_\lambda =< \Gamma_{\lambda i} > \times m_{\lambda i}$ and two-step cascade intensity $I_{\gamma\gamma} = \Sigma_{J,\pi}( \Gamma_{\lambda i} / < \Gamma_{\lambda i} > m_{\lambda i}) \times n_{\lambda i} \times (\Gamma_{if} / < \Gamma_{if} > m_{if})$ connecting compound state $\lambda$ with the given low-lying levels of nucleus *f* and exciting at the same time $n_{\lambda i} = \rho_i \Delta E$ intermediate states *i* from any interval of ΔE width can be reproduced in calculation within the experimental precision. This circumstance allowed us to obtain unique information about ρ and *k*, as an infinite number of possible DL and RSF (each of which allows to reproduce $\Gamma_\lambda$ and $I_{\gamma\gamma}$ accurately) lies in a very narrow interval of their value variation for any of γ-quantum energy and nucleus excitation $E_{воз} < B_n$.

Methods [3] have 2 most important sources of error in determination of ρ and *k*:

a) the error in determination of the $I_{\gamma\gamma}$ absolute value and

b) the error in separation of experimental spectrum of two-step cascades into two symmetric parts, which depend on energy of only primary $E_1$ and only secondary $E_2$ cascade transition.

The error in determination of intensity is easy to control, if a large statistics of useful events allows one to determine peak areas in the sum coincidence spectrum of cascades to the final levels with the excitation energy $E_f$ not less than $\approx 0.5\ B_n$. Their simple correction for registration efficiency and probability of the useful coincidence loss easily available for experimental determination because of the third and subsequent quanta of cascades registration allows to determine the sum of cascade intensities and direct transitions to the lowest cascade levels. This sum may exceed 100% only if $I_{\gamma\gamma}$ is too high. Its experimental value varies from ≅ 70% for W isotopes to ≅ 90% for *Os* isotopes with the value of $2.0 < E_f < 2.5$ MeV, respectively. On the basis of these data and different model calculations we can assume that relative errors in determination of $I_{\gamma\gamma}$ are of the same scale as errors in determination of the sections of thermal neutron capture (10-20%).

All measured in the experiment distributions of cascade intensities represent a superposition of a certain number of pairs of peaks having different intensity and “noise” line with zero mean value (the result of background subtraction). That is why, at a rather high statistics of coincidence from any spectrum of two-step cascade connecting compound state and given low-lying level, it is practically possible to extract even in any deformed nucleus several hundreds of pairs of resolved intense peaks, which corresponds to 90 and more per cents of cascade intensity with the energy of their intermediate level less than $\leq 0.5\ B_n$. Using the maximum likelihood method for these cascades it is possible to determine [6] γ-ordering in cascade. At the same time the energies of nucleus levels are defined with a rather high degree of reliability and the transitions are placed in the γ-decay scheme.

Then the intensities of the cascades with primary transitions and with energy $E_1 > 0.5B_n$ placed [6] in the decay scheme are subtracted [4] from experimental spectra. The remaining part of

spectrum is, basically, a superposition of intensities of a large number of cascades with primary transition energy less than $0.5B_n$ and "noise" distribution with zero mean. Since there exists a non-zero threshold of cascade intensity $i_{\gamma\gamma}$ with primary transitions and energy $E_1 > 0.5B_n$, the intensity and quantum energies of which can be derived from spectrum, the procedure [4] may slightly overstate the value of total cascade intensity with $E_1 < 0.5B_n$ and, consequently, understate it for the equal value for symmetric energies of cascade quanta.

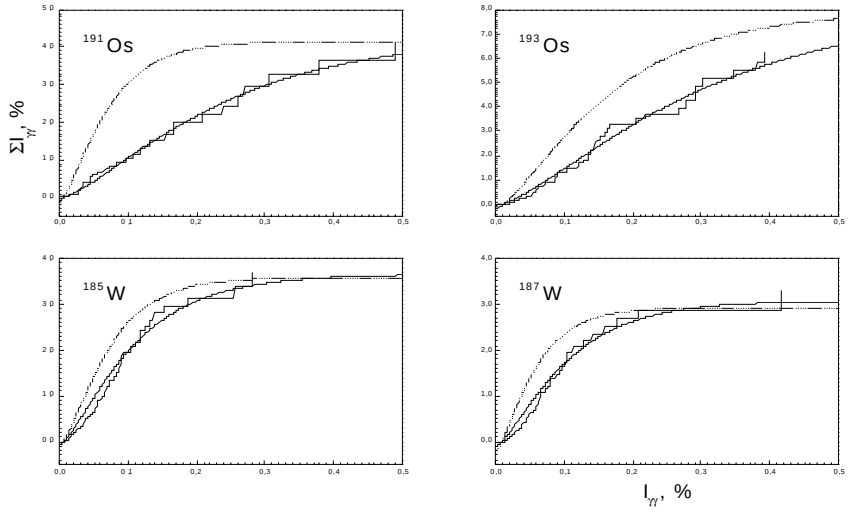


*Fig. 1. Cumulative sums of $I_{\gamma\gamma}$ intensity experimentally observed in $^{185,187}$W and $^{191,193}$Os cascades (histogram) for the energy interval of their intermediate level from 2.5 to 2.75 MeV (% of compound state decays), the approximated dependence (solid line) and the expected one for number of levels, predicted by model [11] (dot line) for the same total cascade intensity.*

The estimation of maximum relative value of the error in question does not exceed several per cents for the last experiments carried out at the spectrometer of high efficiency coincidences in Rez [8]. This can be seen on fig. 1 showing an example of approximation [9] of cumulative sums of all cascade intensities populating one and the same intermediate level in the interval near $0.5B_n$ of excitation energy for four nuclei under consideration: $^{185,187}$W and $^{191,193}$Os. Similar data were obtained for lower excitation energies. Module of extrapolated dependence for $i_{\gamma\gamma} = 0$ determines the expected absolute value of intensity for low-intensity cascades with energy of their intermediate level within the mentioned interval of values.

As follows from the data analysis of such type for other intervals below $0.5\ B_n$, in modern experiments the intensity part of low-intensity cascades with $E_1 > 0.5B_n$, which were not extracted from spectrum and, thus, not placed in the decay scheme, does not exceed $\cong$ 1% if only the deviation of primary transition intensities from the mean value is described by the Porter-Thomas distribution [10] (or by any other one with smaller dispersion).

The error of such scale, as seen from modeling, does not introduce any principle changes into the obtained, in accordance with [3], energy dependences of LD (fig. 2) and RSF (fig. 3). Such verification was performed under the assumption that cascade intensities are overestimated by 50 % in the analyzed nuclei. The result of modeling is given in the same figure for comparison.

New and, apparently, the most precise for today experimental data concerning two-step cascades in W and Os isotopes confirmed the necessity for improvement in theoretical description of nuclear properties in the region of transition from "simple" states at $E_f \leq$ 1-2 MeV to the very complicated states (for example, to neutron resonances). Observation of the step-like change in the dependence of LD confirms the conclusion made in [3] about the irrelevance of notions of "smooth" changes in nuclear properties during the transition from "order" to "chaos".

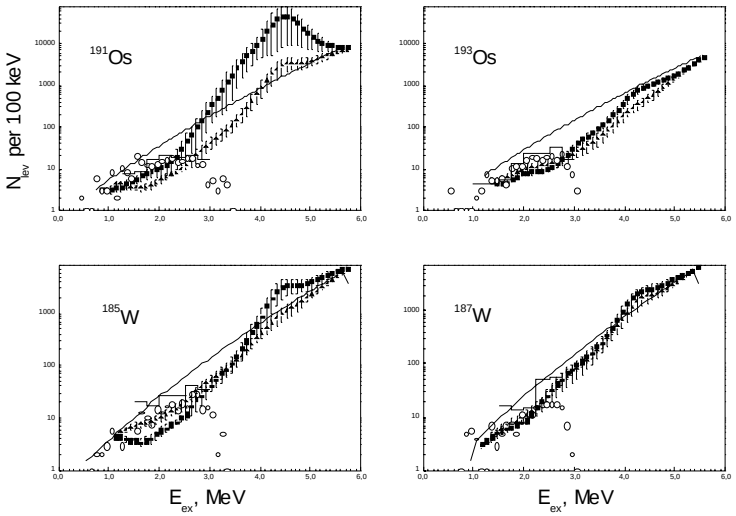


*Fig. 2. Number N of levels of both parities excited by dipole primary transitions. Circles represent a number of experimentally observed intermediate levels of two-step cascades, histogram represents their most probable expected values for zero threshold of cascade registration [9]. Points with error bars show the most probable values reproducing $\Gamma_\lambda$ and $I_{\gamma\gamma}$. Lines represent calculations according tomodel [11]. Triangles represent the mean value of LD reproducing the values of $I_{\gamma\gamma}$ from fig.1 diminished 1.5 times.*

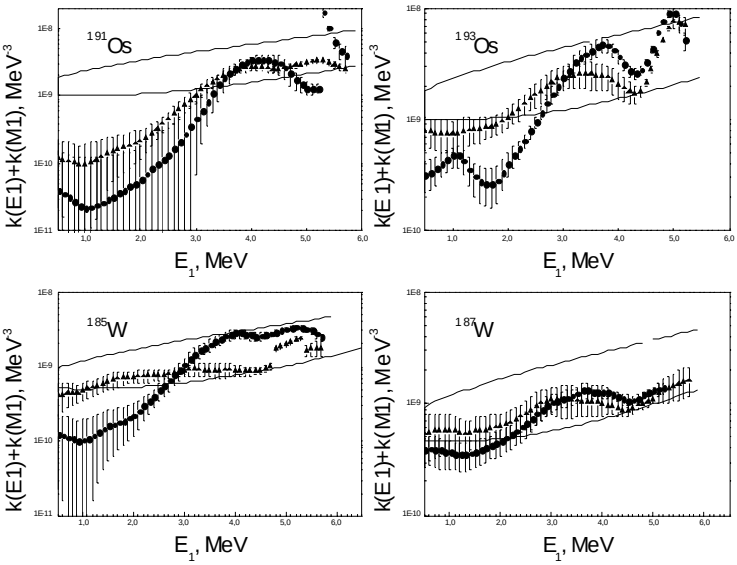


*Fig. 3.The most probable sum of strength functions k(E1)+k(M1) of E1 and M1 transitions of radiative thermal neutron capture with its calculated error in the function of the cascade $E_1$ primary transition energy. Solid lines represent the data of model notions [12, 13] summed with the normalized to experiment value k(M1) = const. Triangles show the same as in fig. 2 for RSF.*

The reliable experimental data obtained recently on the parameters of cascade γ-decay process of excited states from the excitation energy region $E_{ex} \cong B_n$ show, at the least, that conventional notions of the nuclear properties below $B_n$ need rather serious correction and further development. And the statistic character notions of γ-decay process evidently fail to provide the reproduction of its experimentally measured parameters within the precision achieved in experiment. The appropriate "statistic" approach leads to underestimation of nucleus structure influence on the parameters, that determine this process, either for the whole interval of $B_n$ excitations, or for its greater part.

# STUDY OF ELEMENT COMPOSITION OF *ARTHROBACTER OXYDANS* BY EPITHERMAL NEUTRON ACTIVATION ANALYSIS

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*Arthrobacter* species are the members of the actinomycete-coryneform bacteria [1]. *Arthrobacter oxydans (A.oxydans),* isolated from Columbia basalt rocks of U.S. DOE contaminated site was identified as Gram-positive Cr(VI) -reducing bacterium by Holman at al. [2]. The ability of bacteria in heavily contaminated sites to survive through the reduction of highly toxic Cr(VI) to less toxic Cr(III) has created significant opportunities to detoxify environment [3].

The purpose of this investigation on the initial stage is to determine the baseline chemical composition of *A. oxydans* using epithermal neutron activation analysis (ENAA) and to study Cr(VI) and Cr(III) uptake by *A. oxydans.*

*A. oxydans* biomass for ENAA was cultivated in the following nutrient medium: 10 g/l of glucose, 10 g/l of peptone, 1 g/l of yeast extract, 2 g/l of caseic acid hydrolysate and 6 g/l of NaCl. To perform chromium accumulation test *A. oxydans* was kept in the nutrient medium described in [4] and Cr(VI) (as $K_2CrO_2$) or Cr(III) (as $Cr(CH_3COOH)_3$) was added to the nutrient medium within a concentration range of 10-200 mg/l in the exponential phase of growth. After being cultivated for 5 days the cells were harvested by centrifugation and rinced twice. This wet biomass was dried according to the procedure reported in [5]. The dry native biomass was finally pelletized using a titanium mould.

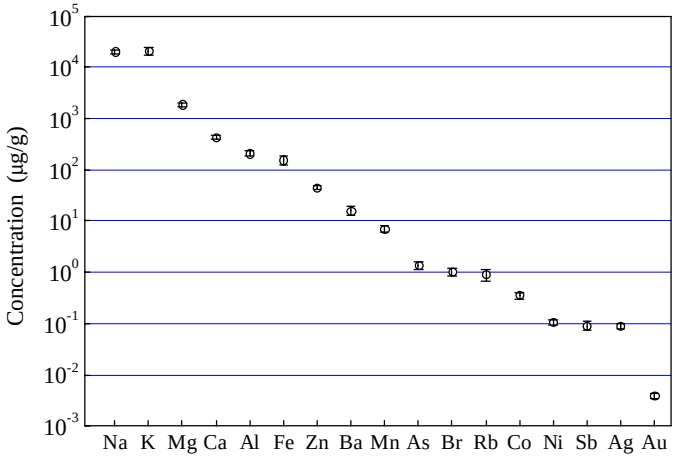


*Fig. 1. Elemental distribution in lyophilized samples of A.*

ENAA of these samples was carried out at the IBR-2 pulsed fast reactor in FLNP, JINR, Dubna. The ENAA technique for biological samples is described in detail in [5,6]. A total of 17 major, minor and trace elements were determined in the biomass of *A. oxydans* (Fig. 1). As it is seen, the concentration range spans more than 8 orders of magnitude. The increased concentrations of Na and K in the samples are due to biomass being freeze-dried in a Na-K phosphate buffer. The concentrations of Mg, Al, Ca and Fe were found to be high. So, it can be supposed that the composition of *A. oxydans* reflects the chemical composition of the environment to wich it was

confined. The Columbia basalt samples from the studied site are fine-grained silicat rocks and magnetite is also often present [2].

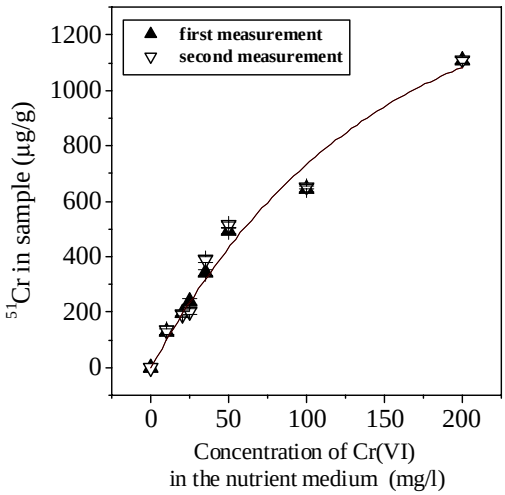


*Fig. 2. Chromium content in A.oxydans cells versus Cr(VI) content in the nutrient medium.*

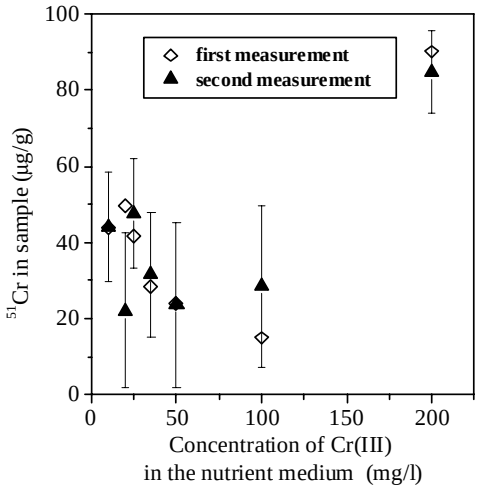


*Fig. 3. Chromium content in A.oxydans cells versus Cr(III) content in the nutrient medium.*

In Fig. 2 and Fig. 3 the results obtained for samples with Cr(VI) and Cr(III) loading are presented. As it follows from Fig. 2, the total content of intracellular chromium always increases, while the uptake of Cr is more intensive in the interval of Cr(VI) concentrations 10-50 mg/l. At 50 mg/l load (during 5 days) the accumulated chromium is about 500 µg/g. It should be noted that, when Cr(VI) concentration exceeds 50 mg/l , the survival ability of *A. oxydans* cells decreases dramatically [4].

Fig. 3 shows that in the investigated range of concentrations the accumulation of Cr(III) in bacterial cells practically does not take place. However, at a concentration of 200 mg/l Cr content in *A. oxydans* cells increases.Taking into account that the rate and extent of chromium penetration into cells dependens on its extracellular concentration and exposure time, one can assume, that at the concentration 200 mg/l ( after 5 days of exposure to Cr(III)) the number of certain complexes of chromium, that have high penetration ability, increases.

The obtained results can be of use for the future investigation of the Cr(VI)-reducing processes in *A. oxydans* and also will be compared with data for other Cr(VI)-redusing endolithic (rock/mineral inhabiting) bacteria.

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# 6. PRIZES

***JINR Prizes:***
**In Experimental Physics Research*:***

First Prize:
*V.V.Nesvizhevsky, H.G.Börner, A.K.Petukhov, A.N.Gagarsky, S.Baeßler, H.Abele, A.V.Strelkov, V.I.Luschikov. «Theoretical prediction and experimental study of quantum states of the neutron in the gravitational field of the Earth».*

Second Prize:
*V.L.Aksenov, A.M.Balagurov, D.P.Kozlenko, S.L.Platonov, B.N.Savenko, V.P.Glazkov, V.A.Somenkov. "Development of techniques for studying the structure and dynamics of condensed matter by neutron scattering under high pressures at pulsed reactors".*

***FLNP Prizes*:**
**In Nuclear Physics**:

First Prize:
*E.V.Lychagin, A.Yu.Muzychka, G.V.Nekhaev, A.V.Strelkov, D.G.Kartasov, V.V.Nesvizhevsky. "Investigation of UCN small heating".*

Second Prizes:
*Yu.M.Gledenov, P.V.Sedychev, M.V.Sedysheva, A.Oprea, G.Khuukhenkhuu, Chen Zemin, Zhang Guohui, J.Andrzejewski, P.J.Szalanski. "Investigation of the (n,$\alpha$) reaction on the middle mass nuclei in interactions with fast neutrons".*

*A.M.Sukhovoj, V.A.Khitrov. "Possibilities of model-independent determination of parameters of nuclei gamma-decay".*

**In Condensed Matter Physics**:

First Prize:
*A.M.Balagurov, V.Yu.Pomjakushin, T.V.Elzhov. «Atomic and magnetic structures, disorder effects and unusual superexchange interaction in oxides $A_2MnGaO_{5+x}$ (A = Ca, Sr) with the structure of lamellar brownmillerite».*

Second Prize*:*
*D.P.Kozlenko, B.N.Savenko, S.E.Kichanov, V.P.Grazkov, V.A.Somenkov, K.M.Podurets, V.M.Ryzhkovsky, V.S.Goncharov. «Investigation of pressure induced spin-reoriented magnetic phase transitions in manganese and ferrum compounds» (series of works).*

Third Prizes:
*T.A.Lychagina, D.I.Nikolaev. «Model investigation to apply to quantitative texture analysis averaging».*

*A.I.Beskrovnyi, S.G.Vasilovsky, A.V.Belushkin, L.S.Smirnov, A.M.Balagurov, M.L.Martinez-Sarrion, L.Mestres, M.Herraiz. «Structure investigation of a new compound $Bi_{2.53}Li_{0.29}NbO_9$ by powder neutron diffraction» (series of works).*

**In Applied and Methodical Physics:**

Second Prize:

*M.V.Frontasyeva, S.S.Pavlov, S.F.Gundorina, V.P.Chinaeva, L.M.Mosulishvili, F.A.Belotserkovskiy, E.I.Kirkesali, A.I.Khizanishvili. «Application of neutron activation analysis to develop new pharmaceuticals» (series of works).*

*Yu.V.Grigoriev, V.V.Sinitsa, Zh.V.Mezentseva, G.L.Ilchev, H.Faikow-Stanczyk. «Resonance structure investigation of total and partial cross sections of Nb, Mo and Pb in the energy region 0.1-200 keV».*

***The JINR young scientists contest:***

**In Condensed Matter Physics:**

First Prize:

*D.P.Kozlenko. «Pressure induced magnetic phase transitions in manganites».*

**In Nuclear Methods in Life Sciences:**

First Prize:

*E.A.Povtoreiko. «Development of software to process neutron activation analysis results».*

Second Prize:

*L.I.Smirnov. «Studies of atmospheric deposition of heavy metals and radionuclides in the South Ural Mountains».*

## I.M.Frank Stipend:

**In Nuclear Physics:**

E.V.Lychagin

**In Condensed Matter Physics:**

D.P.Kozlenko

**In Methodical Physics:**

V.V.Zhuk

# 7. SEMINARS

| Date | Authors | Title |
|---|---|---|
| 14.02.2002 | I.G.Mitrofanov (Inst. For Space Res., Moscow)<br>V.N.Shvetsov (FLNP JINR) | First Results obtained with the Russian High Energy Detector HEND on board the NASA Spacecraft “2001 MARS ODYSSEY” |
| 25.04.2002 | V.L.Aksenov (FLNP JINR) | Fullerenes. Present and future (on the basis of Proceedings of the XVI European Conference on Molecular Nanostructures) |
| 19.12.2002 | B.N.Zakhariev<br>V.M.Chabanov (BLTP JINR) | Obedient quantum mechanics. New theory status in approach to the inverse problem |

# 8. ORGANIZATION AND USER INTERACTION

## 8.1. STRUCTURE OF LABORATORY AND SCIENTIFIC DEPARTMENTS

**Directorate:**
Director:
A.V.Belushkin
Deputy Directors:
N.Popa
V.N.Shvetsov
Scientific Secretary:
V.V.Sikolenko

**Reactor and Technical Departments**
Chief engineer: V.D.Ananiev
**IBR-2 reactor**
Chief engineer: A.V.Vinogradov
**Department of IREN**
Head: V.G.Pyataev
**IBR-30 booster + LUE-40 Group**
Head: S.A.Kvasnikov
**Mechanical maintenance division**
Head: A.A.Belyakov
**Electrical engineering department**
Head: V.P.Popov
**Design bureau**
Head: A.A.Kustov
**Experimental workshops**
Head: A.N.Kuznetsov

**Scientific Departments and Sectors**
**Condensed matter department**
Head: V.L.Aksenov
**Nuclear physics department**
Head: Yu.N.Kopatch
**Department of IBR-2 spectrometers complex**
Head: A.V.Belushkin
**Nuclear Safety and applied research sector**
Head: E.P.Shabalin

**Administrative Services**
Deputy Director: S.V.Kozenkov
Secretariat
Finances
Personnel

**Scientific Secretary Group**
Translation
Graphics
Photography
Artwork

## CONDENSED MATTER DEPARTMENT

| Sub-Division | Title | Head |
|---|---|---|
| **Diffraction sector. Head: A.M.Balagurov** | | |
| Group No.1 | HRFD | V.Yu.Pomjakushin |
| Group No.2 | DN-2 | A.I.Beskrovnyi |
| Group No.3 | DN-12 | B.N.Savenko |
| Group No.4 | NSVR | A.N.Nikitin |
| Group No.5 | SKAT | Ch.Scheffzük |
| **Small-angle neutron scattering group. Head: V.I.Gordeliy** | | |
| **Neutron optics sector. Head: V.L.Aksenov** | | |
| Group No.1 | REMUR | Yu.V.Nikitenko |
| Group No.2 | REFLEX | V.I.Bodnarchuk |
| **Inelastic scattering group. Head: I.Natkaniec** | | |
| **Biophysics investigations group. Head: I.N.Serdyuk** | | |

## NUCLEAR PHYSICS DEPARTMENT

| Sub-Division | Title | Head |
|---|---|---|
| **Sector 1. Correlation γ-spectroscopy and development of experimental installations. Head: N.A.Gundorin** | | |
| **Sector 2. Polarized neutrons and nuclei. Head: Yu.D.Mareev** | | |
| Group No.1 | Polarized nuclear targets | Yu.D.Mareev |
| Group No.2 | Thermal polarized neutrons | M.I.Tsulaya |
| **Sector 3. Neutron activation analysis. Head: M.V.Frontasyeva** | | |
| Group No.1 | Analytical | M.V.Frontasyeva |
| Group No.2 | Experimental | S.S.Pavlov |
| **Group No.1** | **Neutron spectroscopy** | **Yu.N.Kopatch** |
| **Group No.2** | **Nuclear fission** | **Sh.S.Zeinalov** |
| **Group No.3** | **Proton and α-decay** | **Yu.M.Gledenov** |
| **Group No.4** | **Properties of γ-quanta** | **A.M.Sukhovoy** |
| **Group No.5** | **Neutron structure** | **V.G.Nikolenko** |
| **Group No.6** | **Ultra-cold neutrons** | **A.V.Strelkov** |
| **Group No.7** | **Neutron optics** | **A.I.Frank** |
| **Group No.8** | **Theory** | **V.K.Ignatovich** |
| **Group No.9** | **Electrostatic generator-5** | **I.A.Chepurchenko** |

## DEPARTMENT OF IBR-2 SPECTROMETERS COMPLEX

| Sub-Division | Title | Head |
|---|---|---|
| **Sector No.1** | **Electronics** | **V.I.Prikhodko** |
| Group No.1 | Analogous electronics | A.A.Bogdzel |
| Group No.2 | Digital electronics | V.F.Levchanovsky |
| Group No.3 | Software | A.S.Kirilov |
| Group No.4 | Local networks | G.A.Sukhomlinov |
| Group No.5 | Technology | A.B.Melnichuk |
| **Sector No.2** | **Spectrometers** | **A.P.Sirotin** |
| Group No.1 | Development | G.A.Varenik |
| Group No.2 | Samples environment | A.P.Sirotin |
| Group | Detectors | E.S.Kuzmin |

## 8.2. USER POLICY

The IBR-2 reactor usually operates 8 cycles a year (2000 hrs.) to serve the experimental programme. A cycle is established as of 2 weeks of operation for users, followed by a one week period for maintenance and machine development. There is a long shut-down period between the end of June and the middle of October.

All experimental facilities of IBR-2 are open to the general scientific community. The User Guide for neutron experimental facilities at FLNP is available by request from the Laboratory's Scientific Secretary.

Condensed matter studies at IBR-2 have undergone some changes in accordance with the experience gained during the last several years. It was found to be necessary to establish specialized selection committees formed of independent experts in their corresponding fields of scientific activities. The following four committees were organized:

| | |
|---|---|
| 1. Diffraction<br>*Chairman* - V.A.Somenkov - Russia | 3. Neutron optics<br>*Chairman* - A.I.Okorokov - Russia |
| 2. Inelastic scattering<br>*Chairman* - W.Nawrocik - Poland | 4. Small angle scattering<br>*Chairman* - L.Cser - Hungary |

Deputy Director, Dr. Nikolae Popa is responsible for the user policy. Deadline for proposal submission is May 16.

The IBR-2 beam schedules are drawn up by the head of the Condensed Matter Department together with instruments responsibles on the basis of experts recommendations and are approved by the FLNP Director or Deputy Director for condensed matter physics. The schedules are sent to Chairmen of Selection Committees.

After the completion of experiments, "Experimental Report" forms are filled out by experimenter(s) and submitted to the Scientific Secretary.

The Application Form and other information about FLNP are available by WWW: http://nfdfn.jinr.ru/

Contact address:

***Dr. N.Popa**, Frank Laboratory of Neutron Physics*
*Joint Institute for Nuclear Research*
*141980 Dubna, Moscow region, Russia*
*Tel.: (+7)-09621-65818, Fax: (+7)-09621-65085*
*E-mail:* popa@nf.jinr.ru

## 8.3. MEETINGS AND CONFERENCES

***In 2002, FLNP organized the following meetings:***

| | | | |
|---|---|---|---|
| 1. | X International Seminar on Interaction of Neutrons with Nuclei (ISINN-10) | May 22-25 | Dubna |
| 2. | JINR-Romanian Workshop on Advanced Materials | March 18–22 | Dubna |
| 3. | II Workshop on Investigations at the IBR-2 Reactor | June 17-19 | Dubna |

***In 2003, FLNP will organize the following meetings:***

| | | | |
|---|---|---|---|
| 1. | XI International Seminar on Interaction of Neutrons with Nuclei (ISINN-11) | May 27-31 | Dubna |
| 2. | XII International Conference on Selected Problems of Modern Physics | June 8-11 | Dubna |
| 3. | International Meeting dedicated to the 95th Anniversary of Nobel Prize Winner I.M.Frank | October 23-24 | Dubna |

## 8.4. COOPERATION

### List of Visitors from Non-Member States of JINR in 2002

| Name | Organization | Country | Dates |
|---|---|---|---|
| G.Pepy | LLB, Saclay | France | 09.01-18.01 |
| V.Lauter | ILL, Grenoble | France | 14.01-26.01 |
| H.-J.Lauter | ILL, Grenoble | France | 17.01-26.01 |
| T.Strassle | PSI, Villigen | Switzerland | 17.01-26.01 |
| M.M.El-Saied | NRC, AEA, Cairo | Egypt | 22.01-24.01 |
| K.Walther | GeoFRZ, Potsdam | Germany | 28.01-23.02 |
| V.Gavrilov | IPE, Riga | Latvia | 02.02-11.02 |
| E.Raitman | IPE, Riga | Latvia | 02.02-11.02 |
| R.Wang | Univ. Leipzig | Germany | 13.02-20.02 |
| I.-J.Veriken | Univ. Utrecht | The Netherlands | 17.02-03.03 |
| V.V.Chupin | Univ. Utrecht | The Netherlands | 17.02-03.03 |
| A.Skomorokhov | TU Darmstadt | Germany | 12.03-19.03 |
| J.Schreiber | IfzP Dresden | Germany | 01.04-17.04 |
| M.Hoelzel | GSI, Darmstadt | Germany | 07.04-19.04 |
| S.Danilkin | HMI, Berlin | Germany | 07.04-13.04 |
| P.-J.Holl | Univ. Strathclyde, Glasgow | UK | 07.04-20.04 |
| A.Podlesnyak | PSI, Villigen | Switzerland | 08.04-11.04 |
| V.Rajevac | PSI, Villigen | Switzerland | 08.04-11.04 |
| A.Skomorokhov | TU Darmstadt | Germany | 11.04-20.04 |
| V.Lauter | ILL, Grenoble | France | 15.04-27.04 |
| M.Rekveldt | TU Delft | The Netherlands | 17.04-21.04 |
| H.-J.Lauter | ILL, Grenoble | France | 18.04-27.04 |
| H.-P.Soltner | FZ, Juelich | Germany | 24.04-29.04 |
| N.Aras | Univ. Bahcesehir | Turkey | 05.05-05.05 |
| A.Gabriel | EMBL, Grenoble | France | 20.05-30.05 |
| O.Steinsvoll | Inst. for Energy Technology, Kjeller | Norway | 20.05-24.05 |
| M.Stalder | Univ. Kiel | Germany | 08.06-30.06 |
| V.Gavrilov | IPE, Riga | Latvia | 15.06-21.06 |
| E.Raitman | IPE, Riga | Latvia | 15.06-21.06 |
| V.Lauter | ILL, Grenoble | France | 17.06-28.06 |
| H.-J.Lauter | ILL, Grenoble | France | 17.06-28.06 |
| M.Rudalics | Univ. Linz | Austria | 18.07-29.08 |

| | | | |
|---|---|---|---|
| H.-J.Lauter | ILL, Grenoble | France | 17.06-28.06 |
| M.Rudalics | Univ. Linz | Austria | 18.07-29.08 |
| L.Baradovski | Univ. Saints Cyril &Methodius, Skopje | Makedonia | 04.08-18.08 |
| M.Kern | Univ. Kiel | Germany | 15.08.31.08 |
| A.Zizzari | Univ. Magdeburg | Germany | 31.08-15.09 |
| H.Krell | Univ. Magdeburg | Germany | 31.08-07.09 |
| G.Mitchell | North Carolina State Univ. | USA | 14.09-15.09 |
| A.Frischbutter | GeoFRZ, Potsdam | Germany | 15.10-22.10 |
| K.Walther | GeoFRZ, Potsdam | Germany | 15.10-02.11 |
| P.Cennini | CERN, Geneve | Switzerland | 23.10.27.10 |
| Jung Keun Ahn | Pusan Nat.Univ. | Rep. Korea | 10.11-15.11 |
| H.-J.Lauter | ILL, Grenoble | France | 10.11-21.11 |
| V.Lauter | ILL, Grenoble | France | 10.11-23.11 |
| E.Raitman | IPE, Riga | Latvia | 10.11-24.11 |
| Kim Guinyun | Kyungpook National University, Taegu | Rep. Korea | 13.11-16.11 |
| Youn Soo Kang | Pusan Nat. Univ. | Rep. Korea | 13.11-17.12 |
| A.Frischbutter | GeoFRZ, Potsdam | Germany | 19.11-25.11 |
| L.Baradovski | Univ. Saints Cyril &Methodius, Skopje | Makedonia | 01.12-25.02.03 |
| E.Kravtsov | Univ. Bohum | Germany | 01.12-14.12 |
| K.Bramnik | TU, Darmstadt | Germany | 02.12-05.12 |
| R.Wang | Univ. Leipzig | Germany | 09.12-16.12 |

## 8.5. EDUCATION

The objective of the FLNP educational program is the training of specialists in the field of neutron methods for condensed matter and nuclear physics research. In the year 2002 in Moscow State University named after M.V.Lomonosov the neutron diffraction division as a part of physics department was opened and it is a basic department for FLNP. In addition to the students of this department, the students of the MSU Interfaculty Center «Structure of Matter and New Materials» carry out their diploma work in FLNP. In the Center the students from the Chemical Faculty of MSU, Higher College of Materials Sciences under MSU, Tula State University, Tula Pedagogical University, Tver State Univesity and other universities of Russia and JINR member-states do the course.

In the year 2002, the traditional annual Spring School on Neutron Scattering for Condensed Matter Research was organized by FLNP in cooperation with MSU. The participants listened to the lectures by eminent scientists and did a series of practical works at the IBR-2 reactor and other JINR facilities under the guidance of FLNP specialists.

# 8.6. PERSONNEL

**Distribution of the Personnel per Department as of 15.01.2003**

| Theme | Departments | Main staff |
|---|---|---|
| -0974- | Nuclear Physics Department | 58 |
| -1031- | Condensed Matter Physics Department | 43 |
| -1012- | IBR-2 Spectrometers Complex Department | 47 |
| -0993- | IREN Department | 13 |
| -1007- | Nuclear Safety Sector | 12 |
| -0851- | IBR-2 Department | 48 |
| | Mechanical and Technical Department | 49 |
| | Electric and Technical Department | 31 |
| | Central Experimental Workshops | 37 |
| | Design Bureau | 8 |
| | FLNP infrastructure: | |
| | Directorate | 6 |
| | Services and Management Department | 22 |
| | Scientific Secretary Group | 5 |
| | Supplies Group | 5 |
| **Total** | | **386** |

**Personnel of the Directorate as of 01.01.2003**

| Country | People |
|---|---|
| Armenia | 2 |
| Bulgaria | 3 |
| Germany | 3 |
| Georgia | 2 |
| Macedonia | 1 |
| Mongolia | 1 |
| Poland | 6 |
| Romania | 6 |
| Russia | 29 |
| Ukraine | 2 |
| **TOTAL** | **55** |

# 8.7. FINANCE

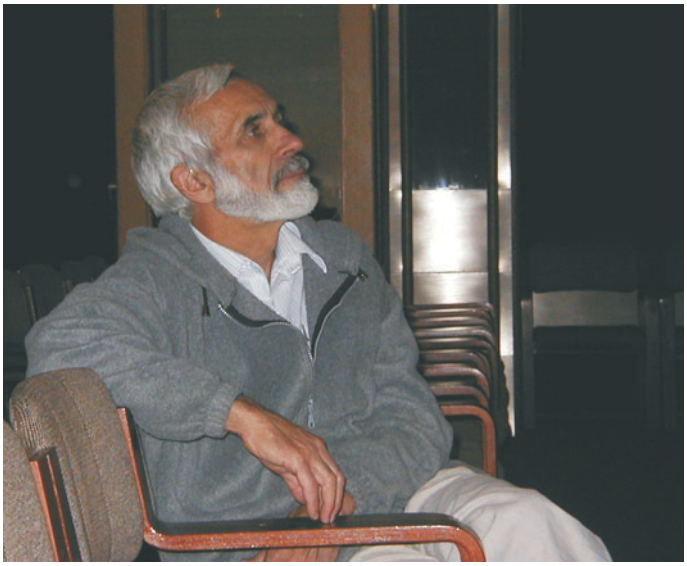
**Financing of the FLNP Scientific Research Plan in 2002 (th. USD)**

| No. | Theme | Financing plan, $ th. | Expenditures for 12 months, $ th. | In % of FLNP budget |
|---|---|---|---|---|
| **I** | **Condensed matter physics** | **4012.3** | **3155.3** | **78.6** |
| | -1031- | 2368.7 | 1461.3 | 61.7 |
| | -0851- | 937.6 | 1346.7 | 143.6 |
| | -1012- | 706.0 | 347.3 | 49.2 |
| **II** | **Neutron nuclear physics** | **1057.1** | **881.3** | **83.4** |
| | -1036- | 622.7 | 462.0 | 74.2 |
| | -0993- | 434.4 | 419.3 | 96.5 |
| **III** | **Elementary particle physics** | | | |
| | -1007- | **6.0** | **10.9** | **181.7** |
| **IV** | **Relativistic nuclear physics** | | | |
| | -1008- | **40.5** | **9.8** | **24.2** |
| **V** | **TOTAL:** | **5115.9** | **4057.3** | **79.3** |

*At 10th International Seminar of Interaction of Neutrons with Nuclei (May 22-25, Dubna)*

*V.N.Shvetsov and V.V.Vasiliev*

*A.B.Popov and V.G.Nikolenko*



*V.I.Furman*

*At 10th International Seminar of Interaction of Neutrons with Nuclei (May 22-25, Dubna)*

*O.Zimmer and A.I.Frank*

*A.V.Voinov and B.V.Zhuravlev*

*Yu.M.Gledenov and A.B.Laptev*

*At the School on Application of Neutron Scattering and Synchrotron Radiation (February 8 - March 8, Dubna). At the centre: V.L.Aksenov, Yu.A.Ossipyan, T.V.Tetereva.*

*M.V.Avdeev introduces students of the School on Application of Neutron Scattering and Synchrotron Radiation to the methods of processing of experimental data obtained at the YuMO small-angle neutron scattering spectrometer.*

*Winners of the young scientist competition of reports presented at the II$^{nd}$ Workshop on Investigations at the IBR-2 reactor. From left to right: V.L.Aksenov, S.Ye.Kichanov, K.N.Zhernenkov, V.Kasperkovjak, S.N.Bushmeleva, D.P.Kozlenko, M.V.Avdeev, S.V.Kozhevnikov, T.V.Tropin.*

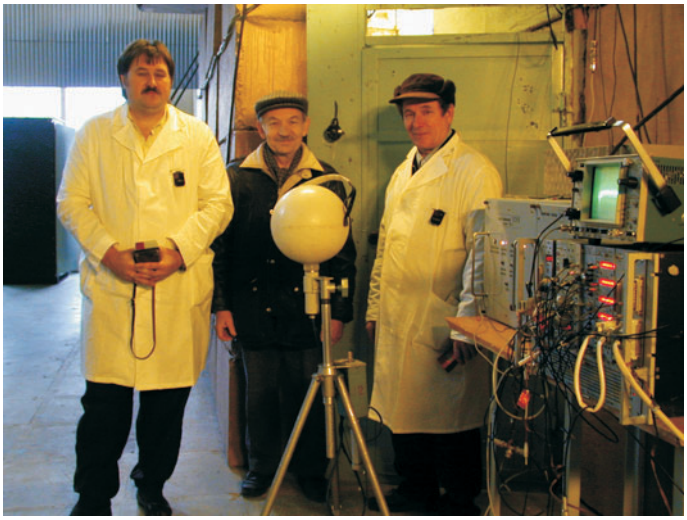
*Excursion of students of Moscow State University to the IBR-2 reactor.*

*V.I.Bodnarchuk demonstrates the possibilities of the REFLEX spectrometer.*
*From left to right: V.I.Bodnarchuk, H.Lauter, V.L.Aksenov, V.A.Ulyanov.*

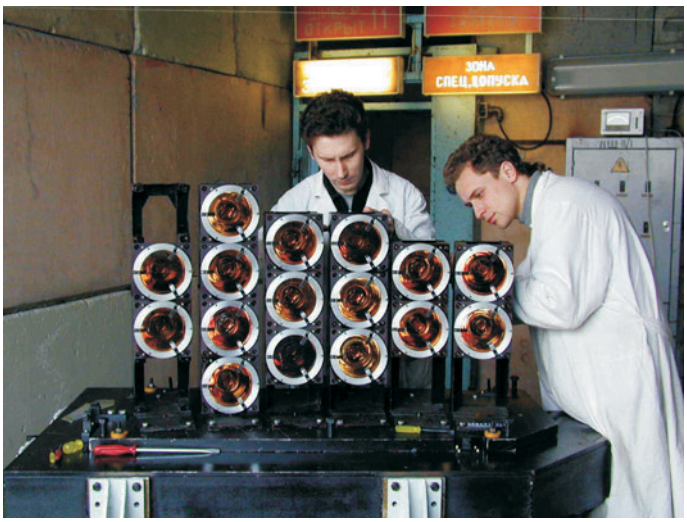
*The REMUR team at the spectrometer after modernization.*
*From left to right: Yu.V.Nikitenko, A.V.Petrenko, H.Lauter, V.L.Aksenov, S.V.Kozhevnikov, V.A.Ulyanov.*

*Ye.V.Lychagin and A.Yu.Muzychka install a setup for measuring UCN small heating.*

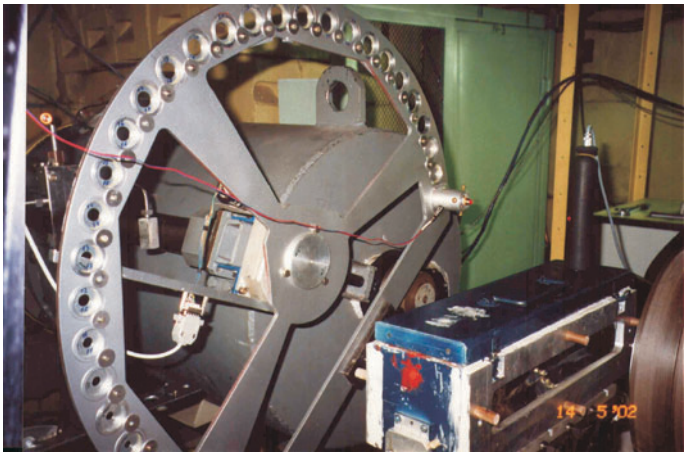
*Installation of a high-voltage electrode of the EG-5 accelerator. From left to right: I.A.Chepurchenko, A.P.Kobzev, Zh.G.Ni.*



*V.V.Alenin, G.S.Samosvat and S.V.Kulikov at the entrance to beam №11b of the IBR-2 reactor.*

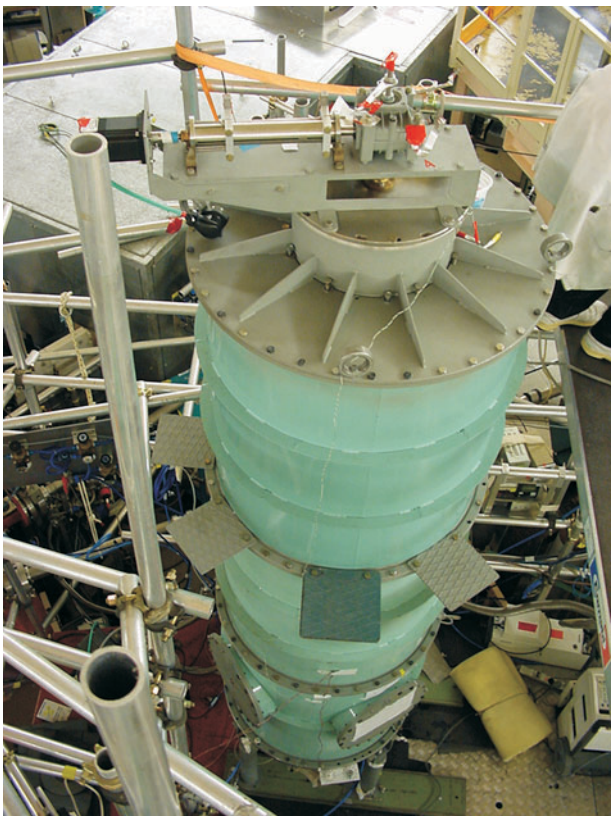



*G.D.Bokuchava and A.V.Tamonov prepare to install a new scintillation detector for the FSD diffractometer.*



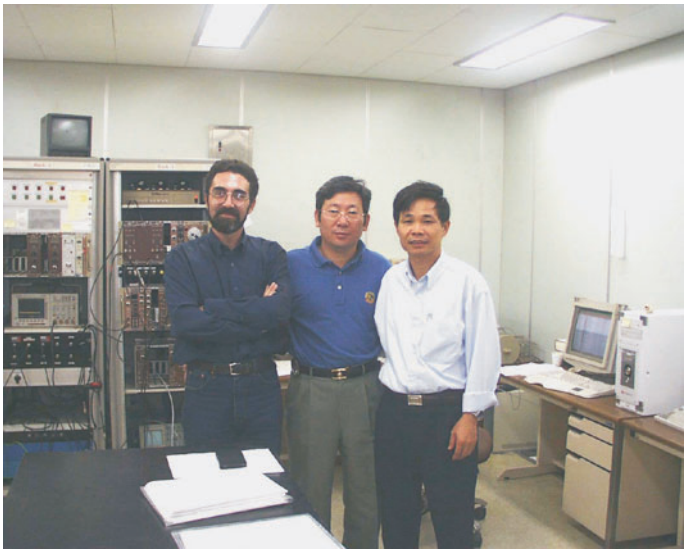
*New collimating system of the YuMO spectrometer.*

*New detector system of the EPSILON diffractometer.*



*The Big Gravitational Spectrometer for measuring UCN small heating (ILL, Grenoble, France).*

*A.V.Strelkov installs samples for measuring UCN small heating (ILL, Grenoble, France).*



*V.R.Skoy, G.R.Kim (Korea) and Van Do (Vietnam) at an electronic module of the TOF spectrometer, PAL, Pohang, Korea.*