1.1. CONDENSED MATTER PHYSICS

1.1.1. EXPERIMENTAL

After the movable reflector at IBR-2 was successfully replaced by a new one in March 1995, physicists of the Department of Condensed Matter Physics (SDCMP) resumed investigations in condensed matter physics by neutron scattering methods with all of the IBR-2 spectrometers. At present, experiments are being carried out with 10 spectrometers: HRFD, DN-2, NSVR, DN-12, SNIM-2, YUMO, NERA-PR, KDSOG-M, DIN-2, and SPN-1. At the REFLEX spectrometer, the adjustment stage is nearing its completion, test experiments have started, and the first physical experiments have been conducted.

As previously, the program in condensed matter physics was divided into four main directions of research: diffraction investigations of ordered structures, investigations of large-scale inhomogeneities by small-angle scattering, neutron-optical investigations of surfaces and magnetic phenomena, and investigations of atomic dynamics in solids by the method of inelastic neutron scattering.

Neutron diffraction. The program initiated in 1994 for investigating novel mercury-containing superconductors continued. The work involved: precision investigations of *Hg*-compounds and accompanying structures with HRFD, *in situ* experiments to reveal the influence of oxygen stoichiometry on structure with DN-2, and the influence of high pressure (up to 50 kbar) on the structure of *Hg-1201* and *Hg-1212* compounds with DN-12. The investigations were carried out in cooperation with MSU, Moscow (E. V. Antipov's group) and RRC KI, Moscow (V. A. Somenkov's group). From the results of the HRFD measurements of $HgBa_2CuO_{4+y}$ compounds with different oxygen contents in the base plane (z=0), namely, y=0.05, 0.11, 0.12, and 0.18, precision structure data (including measurements at T=8 K) were obtained and the influence of oxygen stoichiometry on the value of T_c was refined. The experiment using a sample with y=0.05 was repeated on the 3T2 diffractometer in LLB (Saclay) and yielded practically coinciding results. Figure 1 shows the dependence of T on oxygen content for *Hg-1201*. The oxygen at site (1/2,1/2,0) is actually a doping atom and by changing its concentration, one can obtain any level of doping.

A monocrystal of $La_2CuO_{4.04}$ was used on HRFD to investigate the phenomenon of macroscopic phase separation in the Bmab and Fmmm phases arising at a low temperature. This is connected with the diffusion of non-stoichiometric oxygen through the volume of the crystal. The high resolution of HRFD allowed not only the splitting of the diffraction peaks to be observed (Fig.2), but also the dimensions of the coherent Fmmm phase areas to be estimated. These dimensions appeared to be different in the directions of the *b*- and *c*-axes and were: L_b=1490 +/- 60 Å, L_c=1020 +/- 20 Å.

On HRFD, the first experiments to measure internal stresses in composite materials were conducted together with IFzP, Germany.

On DN-2, investigations in the real-time mode (diffraction and small-angle scattering) of metallic copper oxidation revealed new peculiarities of the process. Decomposition of the *CuO* oxide film (initially covering the copper granules) occurred at 210°C, while copper oxide in a massive state decomposes only at T>1050°C. Simultaneously with the decomposition of the oxide film, an anomalous extension of the metallic copper lattice was observed. At 210°C, a sharp increase in the small angle scattering over the momentum transfer area, corresponding to

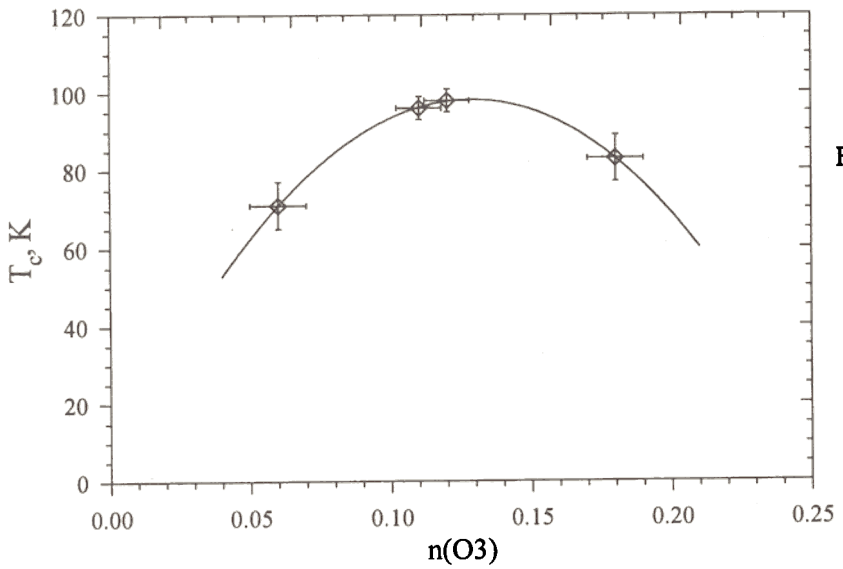
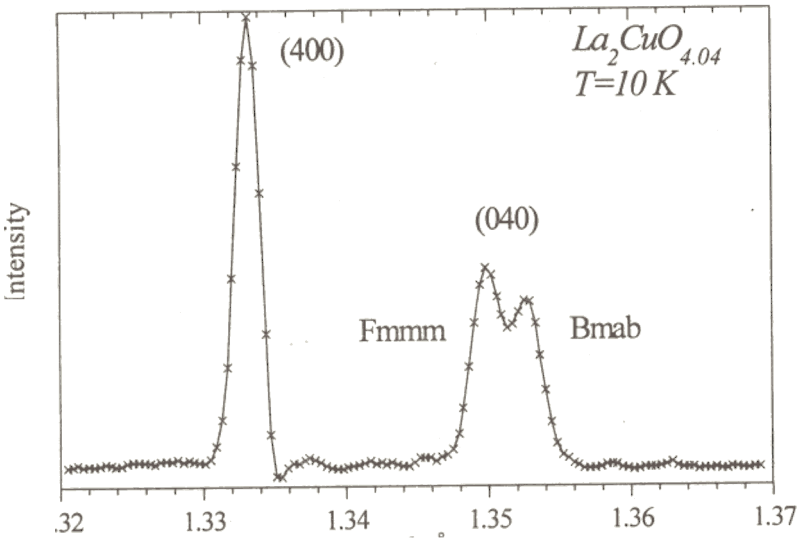


Fig.1 The dependence of the superconducting transition temperature on the value of y for $HgBa_2CuO_{4+y}$ compounds. Experimental points are approximated to the conditional parabolic dependence.



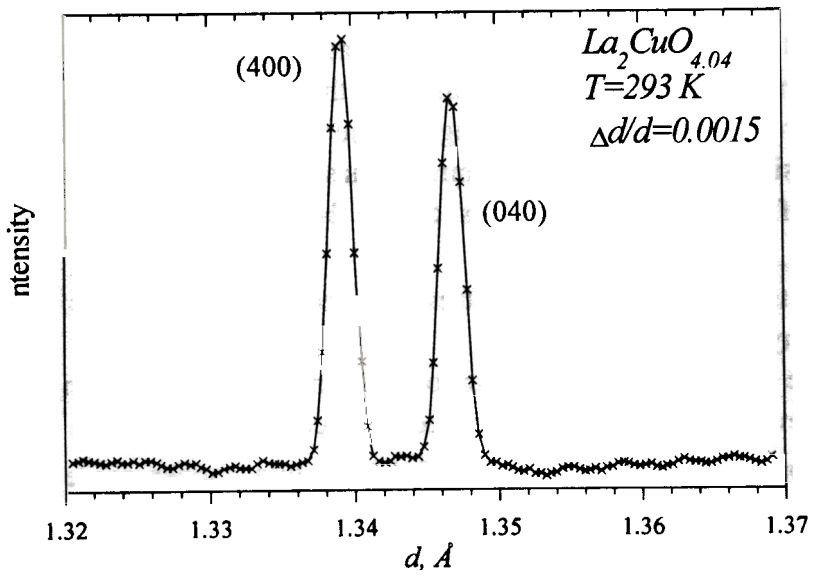


Fig.2 Diffraction spectra (in the vicinity of the (400) peak) from the $La_2CuO_{4.04}$ monocrystal with T_c=38 K as measured with the HRFD diffractometer. At room tempera-ture, two reflexes corresponding to two orientations of 90°-domains in the sample can be observed. At low temperatures, the (040) peak splits into two components corresponding to two structural phases.

the dimensions of 100–200 Å, was observed and the diffraction lines from Cu_2O, and later from CuO appeared. The sequence of these events allows one to assume that the oxidation mechanism of finely dispersed metallic copper covered with a CuO film is an explosive type.

Small-angle neutron scattering. In the reported year, a large number of proposals for experiments with the YUMO small-angle scattering spectrometer were received. In addition, investigations in the frame of long-term joint programs continued with the participation of Germany, France, Slovakia, Czechia and Hungary.

In the experiments conducted together with Germany, glass with CdS_xSe_{1-x}–type admixtures, which radically change the properties of the glass, was investigated. The dimensions of defects arising in the glass, whose radii of inertia appeared to be equal to 27 Å, were determined.

Investigations to study the structure of particles formed in the process of thermotropic micelle-lamellar transitions were begun. This direction of research is connected with the fundamental problem of the mechanism of self-assembly in membranes, as well as with the applied problem of studying the influence of bile salts on biological membranes.

Measurements of *DMPC*–Sodium Cholate *(NaCh)* and *DPPC–NaCh* were performed with small-angle spectrometers in Dubna and Budapest. Structures of particles in the initial and final stages of the thermotropic transition were determined. Figure 3 shows small angle scattering spectra from micelle, created from high *NaCh* concentrations at room temperature. Division of the lipid-detergene system into two phases under the action of temperature was discovered. In this case, the upper phase in *DMPC–NaCh* mixtures has a scattering anisotropy which is evidence of self-orientation of the formed particles.

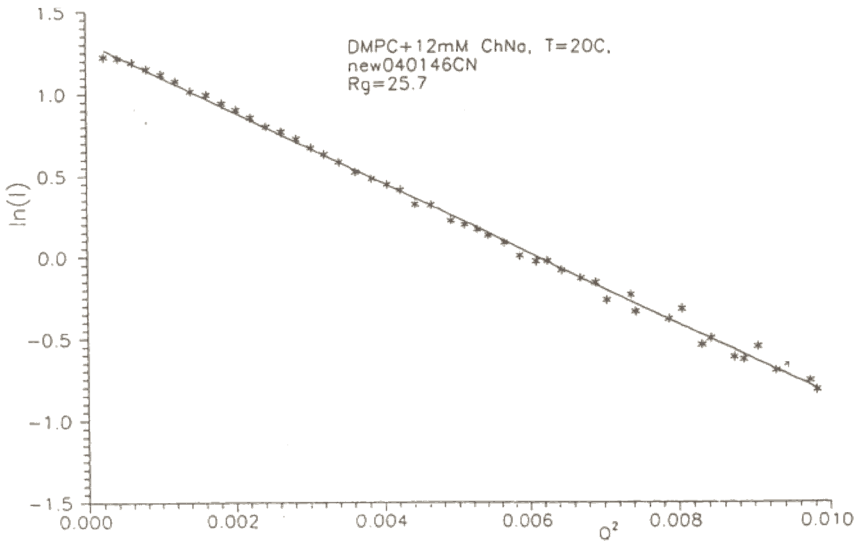


Fig.3 The Guinier plot of DMPC in a *NaCh* mixture at room temperature. The slope of the curve corresponds to the radius of inertia of 25.7 Å.

Experiments to investigate the influence of external pressure on the properties of $C_{14}DMAO/C_{14}TMABr$-based self-organizing micelle systems were continued in cooperation with the University in Bayreyth, Germany. Phase transitions were observed at T=28°C and T=52°C

for pressures of 1.5 and 2.3 kbar, and the first phase diagram of this system was constructed. On the basis of general principles, it was demonstrated that the change in entropy connected with phase transitions is negative, i.e., the entropy of high pressure phases is lower than the initial phase entropy and, thus, they are better ordered.

Polarized neutron investigations in neutron optics. Experiments to investigate the reflecting properties of periodic multi-structures built of ^{56}Fe and ^{57}Fe layers were started on SPN-1. It is expected that such layers will be an effective neutron monochromator.

Reflectrometric measurements of a new type composite material, polymeric lamellar structures with inclusions of $-Fe_2O_3$ particles with sizes of about 40 Å, were conducted. The purpose of the measurements was to obtain data about the distribution of inclusions over structure and the possibility of lamellarity violations.

The stage of neutron reflectometry studies (together with the University in Meinz, Germany) of the formation process of multilayer polyionic films obtained by precipitation from electrolytic salt solutions, was completed. The obtained data convincingly proved the periodic nature of the polymeric structures produced by this technique.

Inelastic neutron scattering. Vibrational spectra of two modifications of highly disperse SiO_2: hydroxylated (saturated with surface OH-groups) and siliconized (OH-groups partly replaced by CH_3-groups), were measured with the KDSOG spectrometer. The measurements demonstrated a strong difference between the vibrational spectra of these two modifications, in contrast to the IR-spectroscopy data. This difference was explained by the presence of torsion vibrations of the CH_3-groups that was seen clearly by neutron scattering.

Measurements of inelastic scattering spectra of different ice phases obtained by a combination of the cooling mode and the external field application mode were conducted with the KDSOG and NERA inverted geometry spectrometers. Figure 4 shows the phonon density for several types of crystal and amorphous states of ice in comparison with usual hexagonal ice.

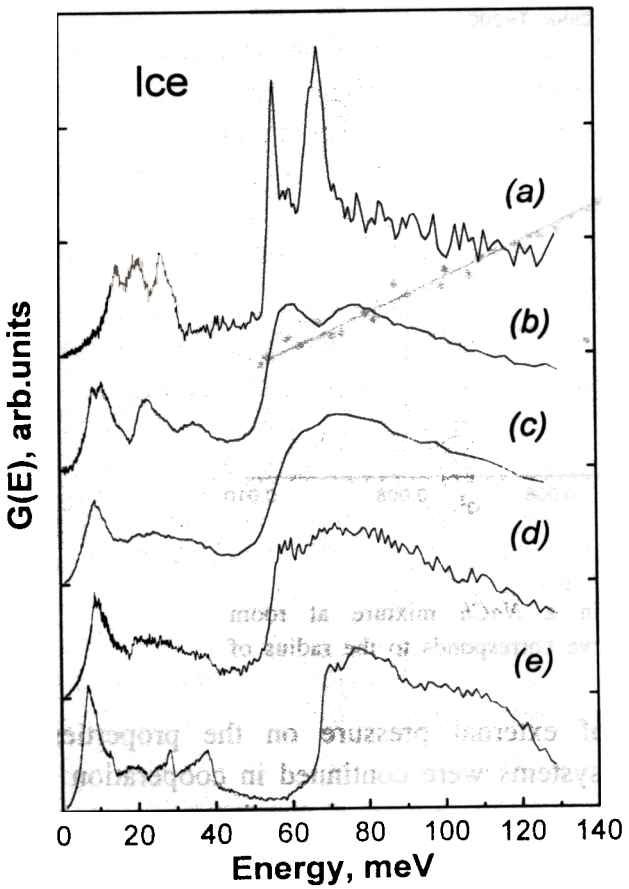


Fig.4 Generalized densities of states for different H_2O ice modifications: (a) crystalline ice-VIII cooled from 340 to 110 K during 20 sec. at 40 kbar; (b) ice-VII obtained by slow cooling to 77 K at 15 kbar; (c) a mixture of hexagonal ice, Ih, and high density amorphous phase ice, hda, compressed to 15 kbar at 77 K; (d) "defect" ice VI' obtained from Ih ice by compressing to 33 kbar at 77 K; (e) ice Ih under normal conditions. The applied pressure was removed from the samples at 77 K and further manipulations were carried out at nitrogen temperatures.

In the experiment conducted together with RRC KI, the dynamic interaction of structural components of the La_2CaCuO_6 compound, the basic compound for lanthanum-containing high temperature superconductors, was investigated. The phonon density of states of the basic compound and the La_2CuO_4 and $CaCuO_2$ compounds forming its layered structure were measured. The phonon spectrum of the basic compound appeared, with good accuracy, to be the sum of the spectra of the structural components. This was evidence of the weakness of the interaction between the layers.

Investigations of the temperature dependence of the structure of the spectra of excited quantum liquids continued on the DIN-2K spectrometer. Simultaneously, calculations to choose a model for approximating the structural dynamic factor of liquid helium were conducted. As the model considerably influences the determined parameters of one-phonon scattering, the choice is of principal importance. The obtained data speaks in favor of the damping harmonic oscillator model.

Development activities. During the reported year, work on upgrading many of the operating spectrometers was conducted.

Complex adjustment of all the elements of the REFLEX-P reflectomer (including the electronics) was performed and the main physical parameters of the reflectometer were measured. On the basis of the obtained data, mutual positionings of collimators and the neutron-optical polarizing system of the reflectometer were corrected during the summer shut-down of the IBR-2 reactor. After additional test experiments, the REFLEX-P will be commissioned and resume regular operations.

On the SPN-1 spectrometer, tests of the new optical elements, the straight and curved soller polarizers, as well as a supermirror, were conducted. All the elements were found to be suitable for further operation, and allow the working wavelength interval to be increased by 2-3 times. In addition, the new optical elements were used to check the inelastic neutron scattering measurement mode over the energy interval from 3 to 50 MeV.

On the DN-12 high pressure diffractometer, experiments to test the second detector ring, installed to analyze inelastically scattered neutron energies and designed for operations with a cooled Be-filter and graphite monochromators, were carried out. Manufacturing of a mirror neutron-guide for this diffractometer was begun and its assembly on the beam is planned for the middle of 1996.

On the high resolution Fourier diffractometer (HRFD), the 20-element detector at a scattering angle of 90° and d-spacing resolution of about 0.003 started operations. This detector will allow the d_{hkl} working interval to be increased considerably in investigations of complex structures. However, that detector is mainly dedicated to investigations of internal stresses in bulk materials.

On the SNIM-2 spectrometer, experiments to measure inelastic neutron scattering from monocrystals (dispersion curves) to reveal additional capabilities of the instrument, which has not been used as a diffractometer before, were performed. The result of the experiment is that SNIM-2 can be successfully used to measure dispersion relationships of magnetic excitations in phase states induced by pulsed magnetic fields up to 200 kOe. In this respect, the SNIM-2 will be without competition until pulsed magnetic instruments are created at other neutron sources.

A large volume of methodological work was conducted to update the NSVR spectrometer. New possibilities of conducting experiments with this spectrometer have appeared and the process of data collection and preliminary processing was radically improved. The new possibilities for conducting experiments include the EPSILON setup, which allows one to

conduct analysis of internal stresses in bulk products. The specialized goniometer which was put into operation allows a sample to be rotated around the vertical axis (the rotation accuracy is better than 0.0025°) and *XYZ*-movement of the sample can be accomplished with an accuracy not worse than 0.0025 mm. In 1995, the NSVR electronics to control experiments and data storage was transferred to VME standard and is currently operating under the control of the OS-9/XWINDOW system. This now allows one to use all the advantages of the multi-task mode and network operations. The SKAT project, foreseeing the complete replacement of the NSVR detector system with the new one, better adapted for measurements of pole figures from textured samples, is nearing its completion.

1.1.2. THEORETICAL

1. The Landau phenomenological theory of phase transition to a polymeric-like phase in AC_{60} *(A=K,Rb)* crystals was developed. The theory correctly describes spontaneous crystal cell strains following the phase transition and also, predicts partial ordering of alkali metal atoms over positions allowed in the octahedral environment of C_{60} molecules. For decreasing temperature, the appearance of another structural phase transition leading to complete ordering of the metal atoms is also possible. The increase in the phase transition temperature in AC_{60} fullerides in comparison with C_{60} is explained.

2. The temperature dependence of mid-infrared (MIR) spectra, the Hall coefficient and the thermoelectric power have been calculated on the basis of a two-fluid model consisting of localized polarons and delocalized carriers. It is shown that in the case of intermediate polarons, the inplane temperature dependence of the optical conductivity is determined by the thermal activation energy and can both increase and decrease with temperature in agreement with the observed results. The same charge carriers were used to calculate the Hall coefficient and the thermoelectric power. The temperature dependence of the Hall coefficient and the thermoelectric power is determined by the same thermal activation energy and the agreement with experiments is good.

3. The PES data were analysed using exact diagonalization with respect to the coupling of the electron with the $A_g(2)$ mode and the truncated Hilbert space for the H_g modes. PES experimental data fitting, just as good as in the papers of other authors for low binding energies, and better than in these papers - for the higher energy region, was obtained. Coupling with high frequency phonons dominates in the electron-phonon interaction. Consequently, the nonadiabatic small polaron theory rather than the adiabatic Migdal-Eliashberg approach should be applied to M_xC_{60}.

4. The behavior of the asymmetric D-SQUID in superimposed RF and DC magnetic fields was rigorously described. Criteria for the determination of the operation regime type were found. A new interesting aspect of RF-pumped SQUIDs which might find applications in future was discovered: following the variation of the magnetic flux of the input signal the behavior of the system radically changes from a nonlinear to a linear one with respect to the RF perturbation.

5. The following well-known paradox was investigated. On one hand, for each quantum system with a time-periodic Hamiltonian, the solutions of the Schrodinger equation, which are the time-periodic functions modulated by the factor $e^{iEt/\hbar}$, exist. On the other hand, the amplitude of the harmonic oscillator, under the action of a time-periodic force with a resonant frequency, increases with time for any initial condition. The paradox is resolved with the help of

the exact solution of the corresponding Schrodinger equation. It is shown, the paradox arises, if one does not take into account the transmutation of the quasienergy spectrum and the steady state (quasienergy state) basis at the resonant point.

6. The high energy asymptotic of the coefficient of the neutron reflection from laminated periodic substances is considered. It is shown that the reflection coefficient depends power-like on the energy and the exponent is defined by the smoothness of the substance potential.

7. It is shown that the magnetic moment of the neutron moving in antiferromagnetics with a spiral-ordered magnetic field, experiences slow precession. The precession pitch strongly depends on the value and the direction of the neutron velocity.

1.2. NEUTRON NUCLEAR PHYSICS

In the course of 1995, experiments to investigate fundamental interaction symmetry violations and electromagnetic properties of the neutron were conducted. A number of investigations in the fields of fission physics, the study of highly excited states of nuclei as well as reactions with the emission of charged particles (related, in particular, to astrophysical problems), were carried out. Work to modernize the existing and create new experimental facilities was also conducted in the reported year. Measurements were performed on beams of the IBR-30 and IBR-2 reactors and other neutron sources of various research centers in Russia, Germany, the USA, China, and France.

1.2.1. EXPERIMENTAL

Parity Violation in Interactions of Neutrons with Resonance Nuclei

Measurement of the P-odd effect following transmission of unpolarized neutrons through a longitudinally polarized ^{139}La target

The experiment was performed on the POLYANA setup of FLNP JINR. A 2 kg ^{139}La sample was polarized by the "rude force" method in the ^{3}He-^{4}He dilution cryostat with an external magnetic field of 1 T. A nuclear polarization $f_N = 0.0065$ was achieved at a temperature of 0.07 K. The transmission effect ε_N is illustrated in Fig 5. From the experimental data, the value of the matrix element of the weak interaction leading to a parity violation $w_{sp} \approx 3.6 \pm 1.2$ meV was estimated.

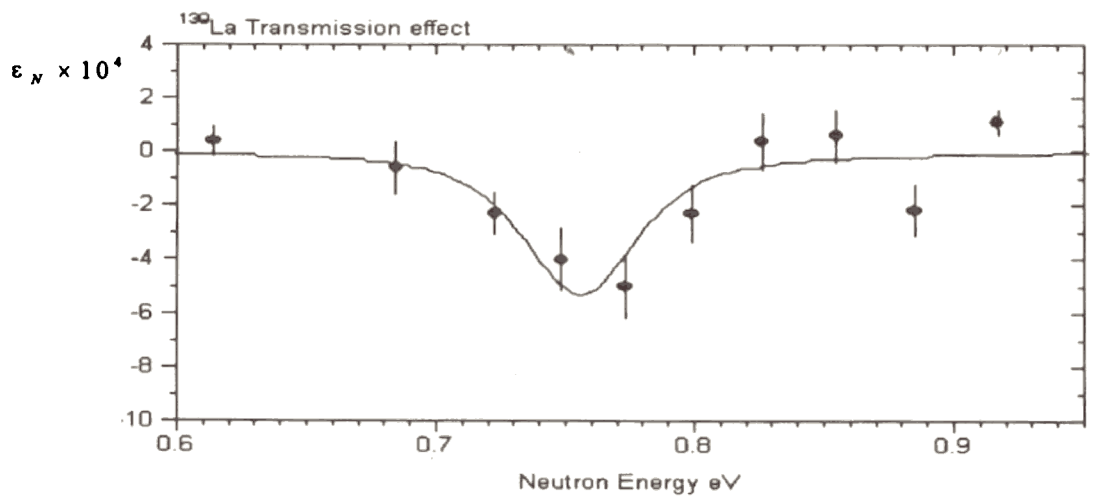


Fig. 5 The transmission effect of unpolarized neutrons through the longitudinally polarized ^{139}La target.

Study of neutron depolarization following transmission through ^{165}Ho

The investigation was performed in the frame of planning an experiment to search for time invariance violation in the P-even, T-odd interaction, which results in the appearance of the

$\vec{s}\cdot(\vec{k}\cdot\vec{I})\left[\vec{k}\times\vec{I}\right]$ correlation, where $\vec{s},\vec{k},\vec{I}$ are neutron spin, neutron moment, and the nucleus spin, respectively. Time violations will be sought in the total interaction cross section of polarized neutrons with an aligned target.

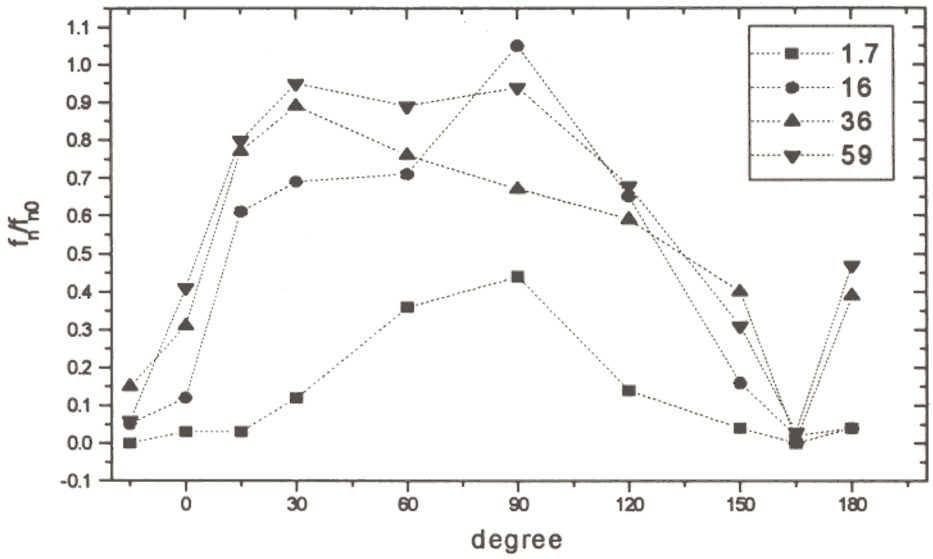


Fig.6 Neutron depolarization in ^{165}Ho.

In the conducted experiment, the transversely polarized neutron beam was transmitted through a cylindrical ^{165}Ho monocrystal. The polarized *Dy* target was used as an analyzer of the neutron polarization at the exit from the sample. The energy dependence of the polarization was measured in *Dy* resonances at 1.7, 2.7, 14, 16, 18, 36, 59 eV. In addition, the dependence of the depolarization on the angle between the neutron and the crystallographic axis *C* was measured. The measurements were conducted at room, nitrogen, and helium temperatures of the sample.

Analogous measurements were carried out using the longitudinally polarized neutron beam. Measurements with different external magnetic fields on the sample, *i.e.*, of 100, 200, and 400 Gauss, were also conducted.

The angular dependence of the depolarization effect expressed as f_n/f_{n0} for the energies of the transversely polarized neutron beam (1.7, 16, 36, 59 eV) is shown in Fig. 6. The obtained results allowed us to estimate the domain dimensions along the *C* axis at a level of 114 μm.

Parity violation: the TRIPLE collaboration experiments

The TRIPLE collaboration, including LANL (Los Alamos), JINR (Dubna), the KYOTO University (Kyoto), TUNL (Durham), TRIUMF (Vancouver), and the DELFT Technology University (Delft), continued measurements of parity violation effects in resonance nuclei with *A~100* to investigate the mass dependence of the matrix element of the weak interaction. The experiments were conducted on the longitudinally polarized beam of resonance neutrons at the LANSCE pulsed source up to the energies of 2000 eV. For the ^{106}Pd, ^{108}Pd, *Sb*, *Cs*, and *I* targets, the helical asymmetry of the resonance cross section was measured by the methods of

transmission and registration of radiative capture gamma-rays. Parity violation effects were observed in many resonances of all of the designated nuclei.

Analysis of the obtained data has begun. Analysis of the effects in 34 *p*-resonances of ^{115}In with energies up to 300 eV, previously measured, yielded the matrix element of weak neutron-nucleus interaction: $M(^{115}I) = 0.59^{+0.25}_{-0.15} meV$. This result, together with the data for *A~110* and *A~230*, point to the permanency of the matrix element *M* for nuclei with the same level density. The statistical method for extracting the matrix element from resonance data containing incomplete spectroscopic information about spins and channel mixing parameters was developed and realized.

Electromagnetic Properties of the Neutron

Precision measurements of the ^{208}Pb total neutron cross section

To estimate the neutron polarizability α_n, measurements of the total neutron cross section σ_t for ^{208}Pb were carried out on the 70 m flight path of the IBR-30 reactor. The classical time-of-flight method with "black" resonance filters was used up to the energies of ~100 eV. The σ_t values were obtained for nine energy intervals within an error of 3-5 mb. To perform energy selection of the keV neutrons, a combination of the time-of-flight method and ^{60}Ni and ^{56}Fe interference filters was used. The experimental points for σ_t at 4.0, 5.1, 6.5 and 24 keV were obtained within an error of 13-18 mb. These new data, though not a record in accuracy, played an important role in promoting further advances towards an exact determination of α_n.

In the analysis of the obtained σ_t, to account for far *s*-resonances, an additional parameter *h*, giving the scattering radius an energy dependence in the form of $R=R_0-hE$ and represented by the sum over all the resonances not accounted for directly was introduced:

$$h = 2276\frac{A+1}{A}\sum\frac{gG_n^{(0)}}{E_0^2} \quad fm/eV. \tag{1}$$

The obtained value was unexpectedly large, $h\rangle 10^{-6}$ fm/eV, which made us return to the detailed analysis of σ_t for ^{208}Pb previously measured in Oak Ridge that gave $\alpha_n = (1.20\pm0.15)10^{-3}\ fm^3$ for the *a* expansion coefficient only:

$$\sigma(k)=\sigma(0)+ak+bk^2+ck^4 \tag{2}$$

Comparing the "mathematical" formula (2) with the physical formula

$$\sigma(E)=\frac{4p}{k^2}\sin^2\left[-k(R_0' - hE + a_pQ)\right]+\frac{12p}{k^2}\sin^2\delta_1 \tag{3}$$

adds two other drawbacks of the corresponding work to these already mentioned, namely, the absence of the *p*-wave contribution (deficit of the coefficient *c* in (2)) and neglect of the term with k^3, which depends only on α_n and is ~12% of the *ak* term for *E*=40 keV.

As far as the parameter *h* is concerned, processing the Oak Ridge data using expression (3) yields $h=(20.4\pm0.3)^{-7}$ fm/eV (in this case $\alpha_n=(1.70\pm0.17)\cdot10^{-3}$ fm^3). For comparison: the strongest (also the nearest) resonance of ^{208}Pb, with E_0=507 keV and $\Gamma_n^{(0)}$=74 eV, would give only $h=6.6\cdot10^{-7}$ fm/eV. Thus, one has to ascertain the presence of at least one previously

unknown strong resonance. Testing of this role for the only $1/2^+$ level below the neutron binding energy in the ^{209}Pb nucleus (the negative resonance with E_0=—1.9 MeV) for $h=0$, leads to α_n =(2.08±0.19)·10^{-3} fm^3 and a resonance width $\Gamma_n^{(0)}$=(2640±30) eV. For comparison: the Wigner width limit is ~2300 eV for a nucleus radius of 8 fm.

In conclusion, it should be said that for the precision determination of α_n, one must either simultaneously look for the k- and k^3-components of $\sigma_t(k)$, or get additional information on unknown s-resonances of ^{208}Pb.

Highly Excited States of Nuclei

Studying the (n,2γ) reaction

Experiments to study the cascade decay of nuclei with the thermal neutron beam of the IBR-30 reactor continued. De-excitation of γ-cascades for the compound states of ^{198}Au, ^{192}Ir, and ^{125}Te nuclei were studied. Under the auspices of an international collaboration (Munich, Grenoble, Darmstadt, Riga), the most complete and reliable decay schemes up to the excitation energy of 2-3 MeV have been constructed for these nuclei.

Analysis of the energy distributions of cascade intensities, aimed at investigating the properties of levels over the nuclear excitation energy range from zero to the neutron binding energy, was also continued. Indications of the possibility that the equidistant bands previously observed for intense cascades can be linearly related to the number of boson pairs in unfilled nucleon shells were obtained, allowing the interpretation of this experimental fact as an exhibition of phonon excitations of nuclei within the the model of interacting bosons.

Experimental determination of the neutron resonance parameters of nuclei with A=100-200

Investigations with the ^{113}In and ^{115}In isotopes continued via the (n,γ)-reaction at ROMASHKA setup and new investigations were started with ^{116}Sn, ^{117}Sn, ^{127}I, ^{175}Lu. In addition to determining the parameters of s-wave resonances, identification of p-wave resonances (^{116}Sn, ^{117}Sn) and their spin determinations were conducted. In the ^{177}Hf + n reaction, spins of 180 previously unknown resonances of ^{177}Hf were measured by the γ-ray multiplicity spectrometry method over the neutron energy interval from 300 to 700 eV.

Nuclear Fission

Angular anisotropy of fission fragments from aligned ^{235}U nuclei

The first stage of measurements of the energy dependence of fission fragments from the resonance neutron induced fission of aligned ^{235}U nuclei was completed. The dependence for the interval of neutron energies from 1.5 to 15 eV, containing over ten s-levels of the ^{236}U compound nuclei, was obtained for the first time. Comparison of the experimental data with a simplified version of the theory illustrated in Fig.7, points to the necessity of including s-levels of different spins in the interference analysis.

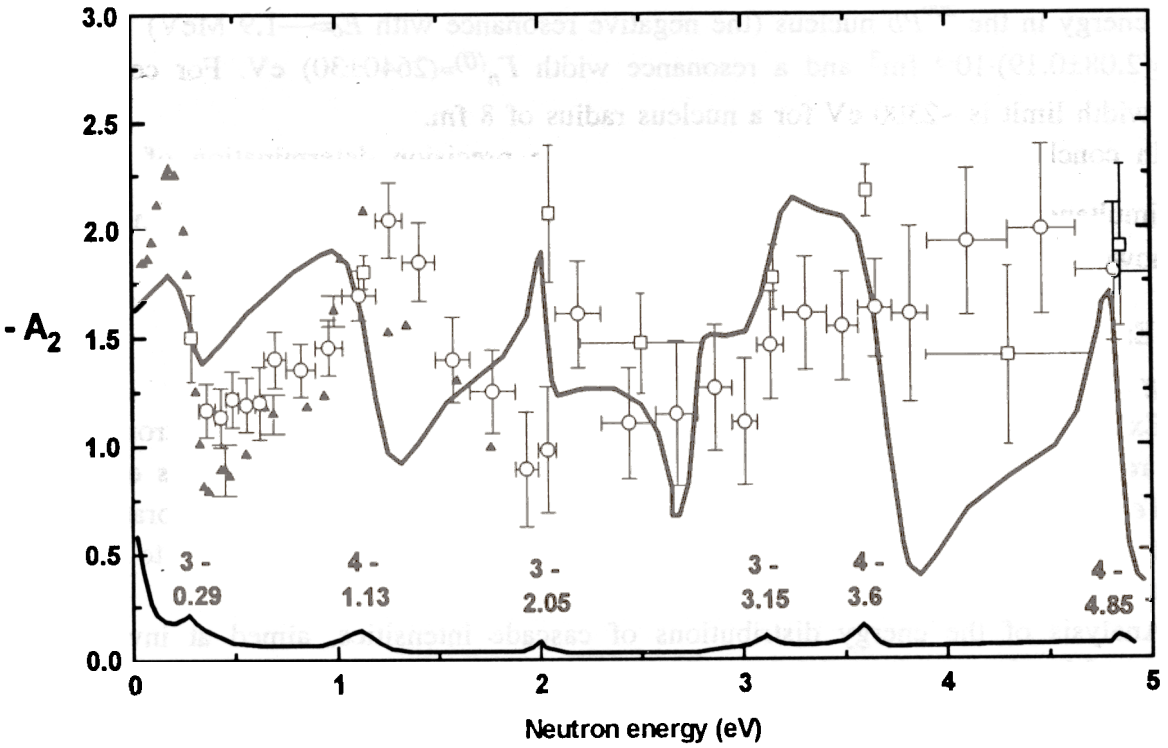


Fig.7 Energy dependence of the angular anisotropy coefficient A_2. Symbols □, Δ display the data by Postma, Pattenden, 1971, 1974; and o display the data obtained in FLNP JINR, 1995. The solid curve presents the theoretical calculations by Moore, 1995.

Fission cross sections and resonance parameters of ^{237}Np in the subthreshold energy region

Time-of-flight experiments to measure the fission cross sections and resonance parameters of ^{237}Np over the subthreshold energy region (3-500 eV) were carried out at the IBR-30 reactor.

Measurements were conducted using fission chambers containing 1.5 g of highly purified plutonium (10^{-6} g/g, of the isotopes ^{235}U, ^{239}Pu) with large fission cross sections. In these experiments fission γ-quanta from ^{237}Np were simultaneously measured by a six-section liquid scintillation detector. The registration of fission events in coincidence with three or more γ-quanta allowed the γ-quanta yield multiplicity to be investigated in separate resonances of ^{237}Np, and as well as in resonance clusters at the neutron energies of 40 eV, 119 eV, and 200 eV related to the levels in the second potential well.

The measurements pointed to the existence of a correlation between γ-yields and the inverse values of the fission widths of the levels. This, in turn, allows the probability of the $(n,\gamma f)$ process to be estimated, including participation of the levels of the second well in the potential deformation energy.

This was the first time that such measurements were conducted for the subthreshold fission region.

Investigating of delay neutrons

In the course of 1995, investigations of delayed neutrons continued on the ISOMER setup in the frame of the collaboration with the 6th subgroup of the Nuclear Data Committee of IAEA. An *Am(Li)* neutron source with a spectrum close to the delayed neutron spectrum was constructed, and a neutron detector was calibrated using the *Am(Li)* and *Cf* sources. The mirror neutron guide on neutron beam 11 of the IBR-2 reactor was reconstructed allowing the thermal neutron output rate at the exit to be increased up to 8×10^5 n/cm^{2}s. New samples from ^{233}U and ^{239}Pu on nickel substrates were prepared to reduce the neutron background from the (α,n)-reaction. As a result, the background in the ^{233}U measurements decreased by 4 times. Measurements of delayed neutron yields using the ^{235}U (50 mg), ^{233}U (67 mg), and ^{239}Pu (170 mg) samples were conducted for cold and thermal neutrons. The energy of the neutrons to induce fission was selected by means of a change of the chopper rotation phase with respect to the starting pulse of the reactor. In the ^{239}Pu measurements, the background amounted to 95% of the total counting rate over the delayed neutron range. The measurements were performed, nevertheless, with a statistical accuracy on the order of 1% and allowed the preliminary value for β_{eff} for ^{239}Pu to be obtained.

To continue the measurements, a new 40 g sample from superpure ^{237}Np purchased. Another new sample (in metallic form) of ^{239}Pu to reduce the background from the (α,n)-reaction will be manufactured.

Studies of the peculiarities of mass and charge distributions of fission fragments from resonance compound states

Under the auspices of the DELRENE program, work to investigate the peculiarities of the fission of actinide nuclei from compound states was carried out. Investigations used the method of gamma-spectroscopy of fission fragments with the aim of identifying the fragments and determining their mass and charge distributions with absolute resolution in *A* and *Z*. Experiments on the precision measurement of prompt gamma-spectra of fragments from the thermal and resonance neutrons fission of ^{239}Pu by at the IBR-30 reactor were completed.

On the basis of the measured intensities of 41 γ-transitions, independent yields of 20 even-even fragments, as well as data on the life-times of four long-lived isotopes were obtained. Comparing the obtained data for the thermal point with known data collected by other methods gives evidence of the adeq uacy of the applied method. Within experimental errors, no variations in relative yields of the fission fragments in the neutron resonances with $J^{\pi}=1^+$ were observed, confirming the theoretical prediction previously made at FLNP for the ^{240}Pu compound nucleus: it undergoes fission only through the $J^{\pi}K=1^+0$ channel.

Further development of the method is connected with increasing the number of fragments identified and the accuracy of the measurements. The high efficiency of anti-Compton spectrometers for such measurements was proved by the results of the methodological experiments on neutron beams.

Investigations of Fast Neutron Induced Reactions with the Emission of Charged Particles

Measurements of the cross sections and angular distributions for the $^{40}Ca(n,a)^{37}Ar$ and $^{64}Zn(n,a)^{61}Ni$ reactions

Investigations of (n,α) reactions induced by fast neutrons are of interest for the purposes of both power engineering and the verification of nuclear models. At present, for the neutron energy range from 3 to 10 MeV which contains the thresholds of many *(n,α)* reactions, the existing experimental data are scarce and significant differences between the results of different authors exist.

The measurements were performed with neutrons from the $D(d,n)^3He$ reaction at the Van-de-Graaf accelerator of the Institute of Heavy Ion Physics, Beijing University, China. The α-particles from the *(n,α)* reaction were registered using the double flat ionization chamber with grids designed at FLNP JINR.

Angular distributions of α-particles for the neutron energies of 4 and 5 MeV were obtained for the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction and are presented in Fig.8. As can be seen, at E_n=4 MeV the angular distribution is practically symmetrical with respect to 90° and has a small forward rise at E_n=5 MeV. This result does not coincide with known data from the literature. For the reaction $^{64}Zn(n,\alpha)^{61}Ni$ at E_n=5 MeV, this symmetrical angular distribution was also obtained.

The integral cross section σ=234±23 mb for the $^{40}Ca(n,\alpha)^{37}Ar$ reaction at E_n=5 MeV obtained in the given experiment is illustrated in Fig.9 with a comparison of the data from other authors and calculated results.

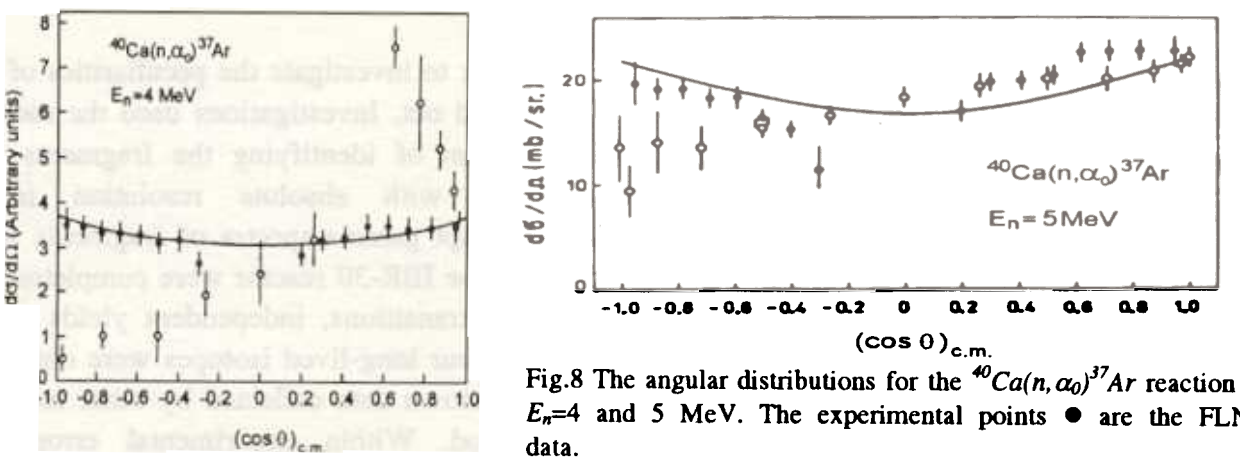


Fig.8 The angular distributions for the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction at E_n=4 and 5 MeV. The experimental points ● are the FLNP data.

Cross section systematics for fast neutron induced (n,α) reactions

Previously at FLNP, an analysis of the isotopic dependence of *(n,p)* reaction cross sections over the neutron energy interval from 6 to 16 MeV was conducted. Recently, the known cross sections of *(n,α)* reactions for the neutron energies of 8, 10, 14.5, and 16 MeV were systematized. To approximate the cross sections, the following formula, analogous to that previously used for *(n,p)*-reaction cross sections, was obtained:

$$\sigma_{n\alpha} = C\pi(R + \lambda)^2 \exp\left[-\frac{K(N - Z)}{A}\right]$$

where $R = r_0 A^{1/3}$ is the radius of the target nucleus, λ is the wavelength of incident neutrons, A, N, and Z are the mass number, number of neutrons, and the charge of the target nucleus, respectively. The parameters K and C are determined by experimental data fitting. The formula was demonstrated to describe the (n,α) reaction cross sections satisfactorily over the range from 8 to 16 MeV.

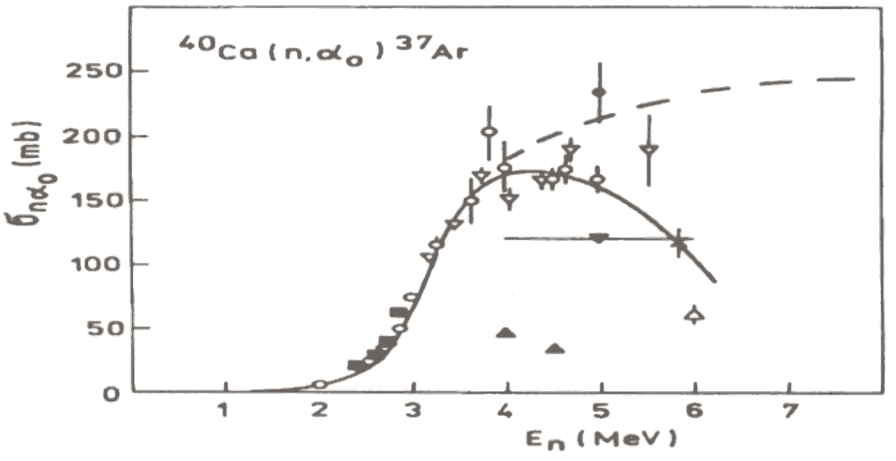


Fig. 9 The $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction cross section. The experimental points ● are the FLNP data. The solid curve illustrates the results of the statistical model calculations.

Astrophysical Aspects of Neutron Physics

Cross sections for the $^{36}S(n,\gamma)^{33}$ and $^{48}Ca(n,\gamma)^{49}Ca$ reactions

Knowledge of the cross sections for neutron induced reactions with elements from the *S-Cl-Ar-Ca*-region at stellar temperatures is of importance to the study of the nucleosynthesis processes. Because the natural content of elements of this region is determined by contributions from different mechanisms (*s*- and *r*- processes, explosion burning, and cosmological synthesis following the Big Bang), one has to carry out a qualitative analysis impossible without an exact knowledge of reaction cross sections in order to analyze the mechanisms of isotope formation. This particularly concerns the problem of the formation of ^{36}S for which many theoretical models give too high a probability for. Previously, the FLNP-Karlsruhe collaboration measured the $^{36}S(n,\gamma)$ reaction cross section for kT=25 keV. This year, measurements of the cross section of this reaction were performed for kT= 151, 176, and 218 keV. Such neutron energies are mainly characteristic of the *s*-process of nucleosynthesis.

The measurements were performed with the 3.75 MeV Van-de-Graaf accelerator in Karlsruhe. A Maxwellian neutron spectrum with the thermal energy kT=25 keV was generated by the $^{7}Li(p,n)$ reaction near the threshold in a thick lithium target (30 μm). Spectra with other energies were obtained by using thinner targets (2.5 μm) and selecting the necessary proton energies. The measurements were carried out with 14 sulfur samples weighing from 20 to 150 mg.

The following cross sections for the $^{36}S(n,\gamma)^{37}S$ reaction were obtained: 187±14 μb, 81±7 μb, and 125±11 μb for the energies of 25, 151, 176, and 218 keV, respectively. The

obtained experimental values are 1.8 times smaller than the estimate previously used in calculations. This means that the ^{36}S yield from the *s*-process is larger by the same factor.

1.2.2. THEORETICAL

Nuclear Fission

Particular progress was achieved in theoretical investigations of nuclear fission. The relationship between asymptotic helicities of fission fragments and the spin projections of fissile nuclei on their axes was established. It was first shown that non-axial separation of fission fragments provides for the existence of P-even and P-odd angular correlations of fission fragments, as well as for the high values of their spins.

Development of a Modified Model of Nuclear Level Density

Following the prediction of the interacting boson model (IBM) about the asymptotic linear relationship between boson energies and the number of boson pairs of nucleons in unfilled shells, an analysis of the data on previously observed quasi-equidistant spacings of the intermediate levels in the most intense two-step cascades was performed. The comparison of the properties of these levels with the IBM predictions gives some indications that the excitations of heavy nuclei with the energies from 1-2 to 4-5 MeV demonstrated in radiative capture reactions are determined, to some extent, by excitation of the nucleon-boson condensate. The known relationships between the nucleon pairing energy, δ, and the phase transition temperature T_c=0.567δ, as well as between the critical excitation energy of the nucleus U_c and T_c: $U_c \cong aT_c^2 \cong$4-5 MeV, together with a hypothesis of the existence of a boson excitation branch, allowed us to explain the longstanding disagreement between the experimentally measured and model-predicted intensities of cascades qualitatively. This disagreement may be connected with the considerable influence, neglected in theoretical calculations, of the phase transition between the Bose and Fermi excitation branches of nuclei.

Non-Stationary Quantum Effects in Neutron Optics

The issue raised in literature of the possibility of distinguishing between pure and mixed states of a neutron beam in an experiment with the help of non-stationary quantum devices was investigated.

It was demonstrated that the long existence of a beam of particles with a non-zero density imposes certain requirements on the quantum characteristics of the beam, namely, on its density matrix. A theory of the phenomenon was developed. In the general case, a beam with modulated density exists, along which waves analogous to sound waves propagate. These waves have a discrete spectrum. The exceptions are two related limit cases: an ideally monochromatic wave which cannot be realized in practice, and a completely mixed (incoherent) state which is probably most frequent in practice. Studies of the time-space structure of the beam, together with spectrometric measurements, allowed conclusions about the density matrix type and answer the posed question.

The role of non-stationary devices is possibly reduced to the purely technical role of transforming the beam frequencies, *i.e.*, to detecting the difference between the modulator and beam frequencies.

The possibility of neutron time-focusing was discussed (together with R.Gaehler from München Technical University). It was found that the possibility of time-focusing neutrons at existing neutron sources with a relatively wide spectra of neutron velocities in the given point of space sufficiently far away from the source. Several ways of creating such time-lenses were proposed. One of them consists of significantly non-stationary action on the wave. For the relationship between the neutron source pulse duration and its image, an expression analogous to that for the usual optical magnification of a thin lens was obtained: $M = -a/b$, where a and b are the source-to-lens and lens-to-detector distances, respectively. The work may be essential for the realization of an old idea of F.L.Shapriro's of storing of UCN from a pulsed source.

Few-Body Problems in Nuclear Physics

Interaction of η-mesons with light nuclei

In recent years, this problem has been in the center of attention of theoreticians and experimentalists since one of the brightest effects of isotopic invariance violation was observed in the $d+d \rightarrow \pi^0 + {}^4He$ reaction. Non-conservation of the isospin and the existence of such a large cross section can only be explained if one assumes that the reaction goes through the creation of a virtual isoscalar η-meson which transforms into an isovector π^0-meson due to $(\eta\text{-}\pi^0)$ mixing. Up to the present time, only attempts at a simplified calculation of this two-step process in the frame of an optical model have been undertaken.

The first microscopic calculation of the subthreshold scattering of η-mesons on ${}^2H$, ${}^3H$, ${}^3He$, and ${}^4He$ nuclei was performed, discovering a quasibound state in the $\eta{}^4He$ system.

Nuclear reactions in muon molecules

Nuclei retained in molecules for a relatively long time can tunnel through the Coulomb barrier and interact with each other via nuclear forces at sub-keV energies. Such conditions cannot be created in scattering experiments. The microscopic analysis of some muon molecules allowed the discovery that among all possible nuclear reactions there is a special class of reactions with relatively large cross sections due to nuclear spectra correlation.

The structure of hypernuclei

The Skyrm-Hartry-Fok method was used to calculate the characteristics of light hypernuclei with a neutron halo (${}^{11}_{\Lambda}He$, ${}^{12}_{\Lambda}Li$, ${}^{12}_{\Lambda}Be$, ${}^{13}_{\Lambda}Be$, ${}^{16}_{\Lambda}C$). On adding a Λ–hyperon, a neutron in the halo can become either more or less bound. The characteristics of the halo strongly depend on the properties of the hyperon-nucleon interaction.

1.2.3. METHODOLOGY

Construction of the UGRA Setup

The construction work in the experimental pavilion was completed. The vacuum chamber with a rotating platform was transported from the JINR Experimental Workshops to neutron beam 6 of the IBR-30 reactor. This chamber, together with the sample movement mechanism and two detector shielding blocks, was assembled on the 250 m flight path. Assembly of the

electric drives and signaling systems was completed. The computer-aided control block was manufactured and the software for future experiments, in the main, was finished. Preparation for test experiments is under way.

Experimental Modeling to Measure Amplitudes of *n-e*-Interactions

Theoretical investigations of the influence of the thermal motion of noble gas (one-atom) atoms on the energy dependence of differential and total slow neutron scattering cross sections were completed. Two versions of experiments to measure the neutron-electron scattering length, b_{ne}, were suggested and simulated:

- measuring the total neutron cross section of the ^{86}Kr isotope, which has a very low capture cross section (~ 3mb) in the interval from 3 meV to 1 – 10 eV;
- measuring the angular anisotropy of the scattered neutrons on natural xenon (better on the $^{132,134,136}Xe$ isotopes) over the interval from 3 meV to 1 eV.

Staging of these experiments is important from the point of view of removing the considerable divergence in the experimental values of b_{ne} and refining the estimate of the mean square charge radius of the neutron.

Modernization of the ROMASHKA Setup

The purpose of this work is to transfer ROMASHKA to the mini-Crystal-Ball class. The protocol for collaboration with the Base for Development and Applications of Physics (BDAP) of the Bulgarian Academy of Sciences was signed, and the mechanical part of the new facility was designed in cooperation with specialists from BDAP. The contract for manufacturing the mechanical part to the account of the Bulgarian dues to JINR has been prepared for signing. Two new measuring modules were put into operation. The first is on the 500 m flight path to support HPGe-detector operations. The module allows multi-dimensional time-of-flight (4K channels) and amplitude (8K channels) measurements to be conducted. The second is on the 123 m flight path of beam 3. The module enables measurements of total transmission and self-indication functions following radiative capture.

Creation of the CSS Anti-Compton Gamma-Spectrometer on the Basis of an HPGe Detector and BGO Scintillators - the DELRENE Project

Calculations to optimize the geometry of BGO scintillators were performed using the GEANT computer code. Model tests of hollow light-guides were conducted. The designs of the spectrometer and its combined passive shielding were elaborated. Two PEM-125-based channels for photon registration were designed and constructed. Thirty-two crystals for the BGO scintillators were ordered and received and their parameters were measured. Manufacture of the structural elements for the spectrometer was completed. The spectrometer will be assembled and put into operation by the end middle of 1996.

Modernization of the Instrument for Measuring Angular Anisotropy of Fission Fragments from Aligned ^{235}U Nuclei

The modernization of the facility was completed: the new refrigerator for continuously maintaining a temperature of 0.1K on a sample was put into operation. New monocrystals of uranium-rubidium nitrate covered by a thin ^{235}U layer, which gives a two-bump distribution of

fission fragments, were installed. Inside the cryostat, implanted *Si*-detectors with an increased resistivity to IBR-30 gamma-pulses were assembled.

Investigation of the Subthreshold Fission of ^{234}U

An ionization fission chamber containing 0.1 g of ^{234}U isotope was manufactured. The daughter product of the α-decay of ^{238}Pu, having a ^{234}U content of over 99.8% and a considerably low (0.08%) admixture of ^{235}U, was used as the material for the chamber layers. Three series of measurements were conducted at the IBR-30 neutron booster. The preliminary results of the measurements (230 hours measuring time) are shown in Fig.10. In addition to the separate isolated resonances, in Fig.10 the first resonance cluster of ^{234}U can be clearly seen in the area around 450 - 650 eV. The measurements and data processing will be continued in 1996.

Investigations of Non-Stationary Quantum Effects in Neutron Optics

Creation of a prototype of an UCN gravitational spectrometer with interference filters was finished. The first series of test experiments was conducted at the IR-8 reactor of the RC "Kurchatov Institute". Simultaneously, investigations of the parameters of the interference filters by the method of neutron reflectometry at the IBR-2 reactor and the method of Rutherford scattering at the EG-2 electrostatic generator, was conducted in cooperation with the Scientific Department of Condensed Matter Physics FLNP. This is necessary for upgrading the technology of filter manufacture. Work to prepare new, improved filters was carried out in cooperation with the Institute for Solid State Physics of the Hungarian Academy of Sciences. An experiment to observe the dynamic multi-ray reflection of neutrons from a ferromagnetic mirror remagnetized

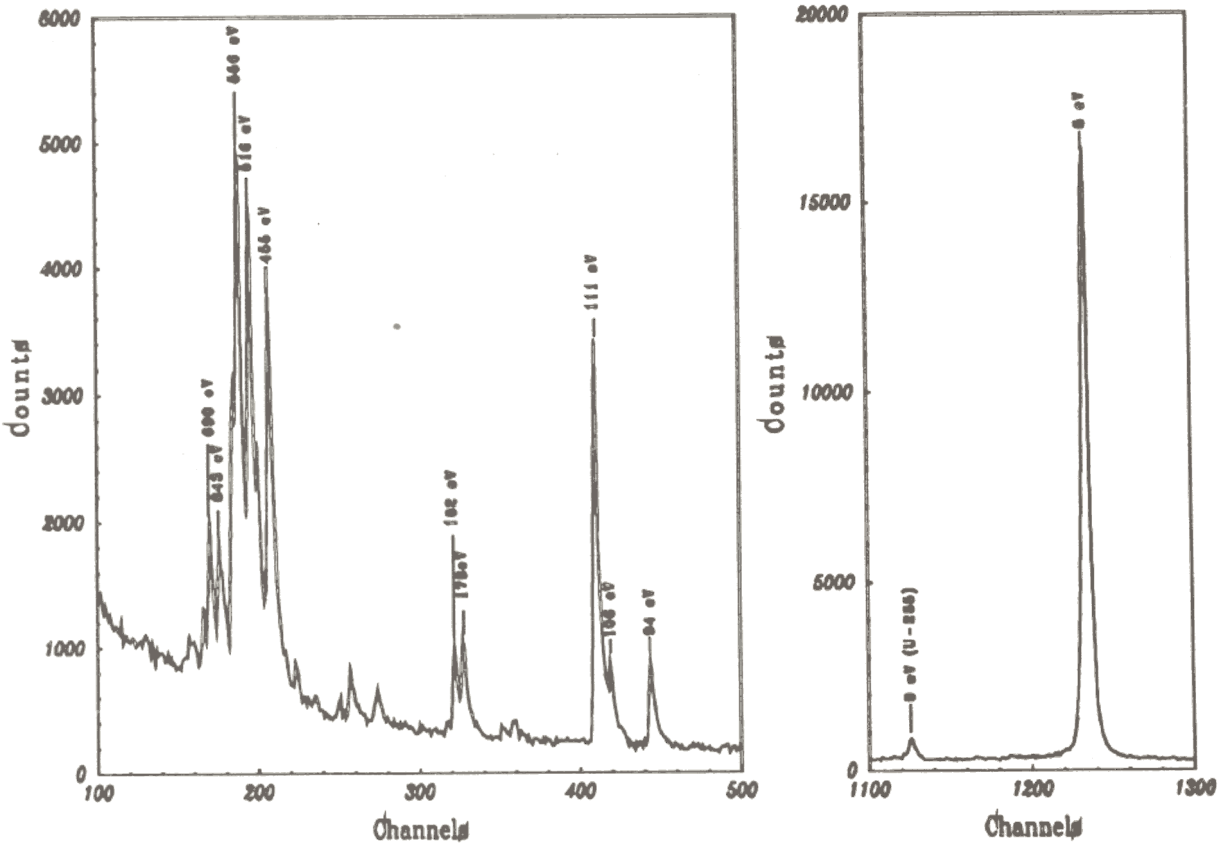


Fig. 10 The time-of-flight fission spectrum of ^{234}U in the energy range up to 1 keV.

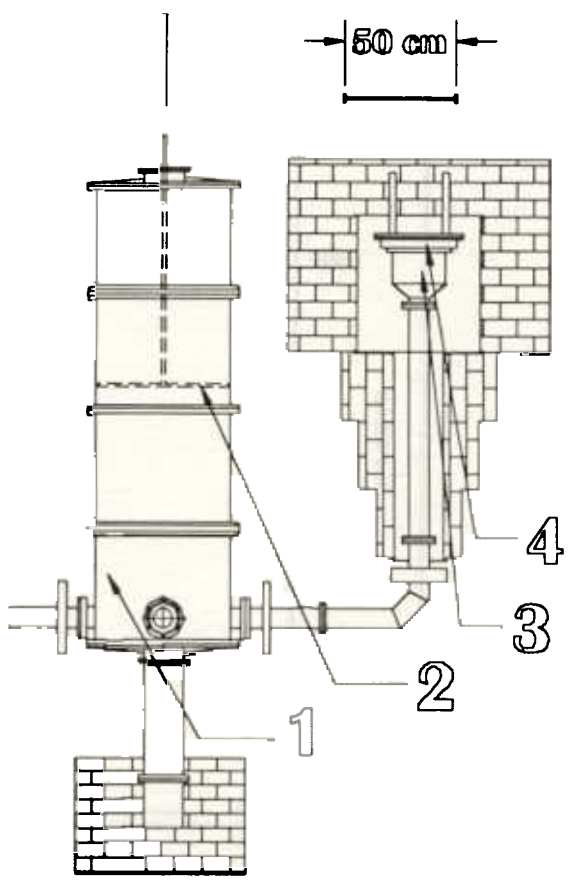
at high frequency is under preparation. The system for generating fields with a frequency of 10 MHz and a strength on the order of 10 Gauss was constructed. Work to manufacture a mirror-sample in cooperation with the Institute of Applied Physics in Nizhnij Novgorod is under way.

Completion of the UCN Pulsed Source

In 1995, complex tests of the facility were completed in Dubna and some of the blocks were corrected. At the end of the year, the facility was moved for installation in the BIGR reactor hall at Arzamas-16.

Creation of a Facility to Search for Weak Heating of Ultracold Neutrons

In 1995, in collaboration with PNPI (Gatchina, Russia), a facility comprising 1 - a spectral filter (storage volume) with 2 - an absorber changing with height, was created and assembled at ILL (Grenoble, France). This facility allows the neutrons heated on 3 - the sample with an area up to 2 m^2 - to be registered. The registration is performed by a ^3He-based detector with variable efficiency - 4. The chamber and detector are surrounded by shielding made of cadmium and boron polyethylene. The background from the detector filled to the ^3He pressure of 400 torr, corresponding to an efficiency of 50% for thermal neutrons, was 0.02 s^{-1}. The expected effect for a foil-sample of 1 m^2 and an UCN intensity on the sample of ~1 $n \cdot cm^{-3}$ is ~1 $\cdot s^{-1}$. In this case, the entire anomaly of UCN storage can be explained by weak heating. Measuring the dependence of the detector count rate on the ^3He pressure provides the possibility of unfolding the spectrum of the heated neutrons.



Here, the sample can have a preliminary outgasing at temperatures up to 400°C. The measurements can be conducted at sample temperature from -195°C to 400°C. The detector of heated neutrons has the same temperature.

Experiments have begun. The difference in the currently conducted experiment from the previous ones consists in the fact that the structure of the facility makes it possible to register the heated neutrons beginning from the energy of ~100 neV (5 m/s). This allows the hypothesis of weak UCN heating (to energies of $< 5 \cdot 10^{-5}$ eV) to be verified as a probable reason for the UCN storage anomaly observed in experiments with different material traps. Combining the capabilities of the facility and the record UCN flux from the ILL source gives basis for an unambiguous verification of the hypothesis.

Non-Stationary UCN Transport. Preparing Experiments of *n-n* Scattering

A method for storing UCN from a pulsed source using a mirror neutron guide and a shutter in front of the storage chamber was proposed. Preparations to conduct experimental tests of the method have started.

Calculations of non-stationary UCN storage and transport through horizontal neutron guides of different configurations and effective UCN filters were performed as well as calculation of the slow neutron background in the neutron scattering experiment at the BIGR reactor in Arzamas-16. Work to optimize the experimental geometry and calculate the detector response function was also performed.

1.3. APPLIED RESEARCH

In the reported period, the Sector of Activation Analysis and Radiation Research (AA and RR Sector) carried out investigations using the REGATA pneumatic-transport facility on beam 11 of the IBR-2 reactor in the following directions.

Neutron Activation Analysis. Data processing was completed and the results of biomonitoring of some regions in the Kola Peninsula were analyzed. For 200 soil and pine-needle samples, concentrations of 30 to 55 elements, including heavy-metal environmental pollutants, were determined. By maximums in concentration distributions, the main environmental pollution sources in the Murmansk region were identified: the big mining and non-ferrous metallurgy plants in the towns of Monchegorsk and Nickel. In the areas around these towns, concentrations of *Ni, Co, Cr, As, Se, Sb, Ag, Fe* and a number of other elements exceeded the allowed upper limit for inhabited regions. The work was carried out in cooperation with specialists from the Kola Scientific Center (KSC) of the Institute of Industrial Ecology of the North. The obtained results were presented at the international conference "Nuclear Physics for Protection of the Environment" (23-28 May, 1995, Dubna) and the national conference "Anthropogenic Soil Changes in Industrial Regions of the North" (25-27 July, 1995, Apatity) and submitted for publication.

In 1995, cooperation with KSC in investigating rare-earth element (REE) distributions in environmental samples from industrial areas in the Kola Peninsula continued. As a result, intense REE environmental pollution sources were revealed. The influence of excess REE concentrations on vegetation, animals, and man, is little studied up to now as the published data on REE contents in environmental objects are scarce. To study REE distributions, 160 soil and pine-needle samples were irradiated and gamma-spectra of the induced activity were measured. Processing of the results is under way.

In 1995, the stage of work conducted together with the Institute of the Lithosphere of Earth (ILE), RAS, to study ecosystems of the Volga and Oka river basins was competed. The results were reported at the international conference in Dubna. In continuation of this work, 100 samples of soil, sediments, and plants were measured to reveal anomalies in pollutant distributions of anthropogenic origin. The results are being processed and will be published in the ILE Report for 1995.

In the reported year, collaboration with the Institute of Chemical Kinetics and Burning, Siberian Branch, RAS (Novosibirsk) to conduct multi-element analysis of atmospheric aerosols

in some regions of Siberia, was initiated. The study of Siberian aerosols is an important and complicated fundamental problem which will be solved under the auspices of an international project "Aerosols in Siberia". Obtaining reliable data on the element composition of aerosols is an important link in these investigations, which will allow the nature and peculiarities of atmospheric pollution sources to be clarified. We investigated 150 aerosol samples from two regions in Siberia, Baikal Lake and Karasuk Lake. The results were transferred to customers for further analysis and the preparation of publications.

In the summer of 1995, members of the AA and RR Sector went on an expedition headed by Scandinavian scientists and supported by the international project "Accumulation of Heavy Metals in North Europe" to collect environmental samples in Romania and Norway. About 300 samples of soil, moss, and lichen were collected for neutron activation analysis at IBR-2.

Irradiation and neutron activation analysis of about 40 technical and jewelry crystals were conducted to investigate the origin of radiation dying and other local centers.

Radiation Investigations. In the reported year, investigations with gamma-irradiation of generation-recombination process singularities in the radiation resistant semiconducting detector material, $TlInSe_2$, continued. The experimental investigation and Monte Carlo calculations showed that the electron filling of local centers in the forbidden band of the semiconductor decreases as the photon energy of the exciting gamma radiation increases. This explains the temperature independence of the current excited by hard radiation in semiconductors such as *CdS, CdTe,* $TlInSe_2$, while the temperature dependence of the photo-current is considerable in these crystals. A paper on the investigation results was submitted to the Russian journal "Physics and Technology of Superconductors".

Together with I. L.Pisarev's group (Laboratory of Nuclear Problems, JINR) work on beam 11 to test the radiation resistance of detectors was started under the auspices of the ATLAS program.

Scientific and Methodological Developments. In the reported year, work to estimate the capabilities of the horizontal and vertical channels of IBR-2 for irradiating materials for the purposes of building new properties in those materials, producing isotopes, and conducting radiation investigations in the field of materials science.

Technical drawings of the irradiation facility for conducting radiation and radiation-analysis investigations of samples in the vertical channels of the water moderator situated behind the movable reflector were prepared and submitted to the Design Bureau.

The new experimental and technological base for the radiation investigations to be conducted in the period from 1996 to 1998 in the frame of the initiated project "Defect Formation in Strongly Anisotropic Semiconducting Crystals", is being created anew. The instrument for investigations of the Hall effect, self- and admixture-photo conductivity, and growing and intercalation of crystals of the $TlSe\text{-}TlInSe_2$ system, was assembled.

In 1995, during the reactor shut-down, the curved mirror neutron-guide (CMNG) on beam 11 of the IBR-2 reactor was adjusted with high precision. As a result, the thermal neutron yield at the CMNG exit was increased by 4 times. Additional adjustment was conducted in connection with the modernization of the instrument for measuring delayed neutron yields with uranium and transuranium nuclear targets. This work is being carried out in cooperation with Yu.S.Zamyatnin's group (FLNP).