Nuclear Physics with Neutrons

Within the scope of the field scientists of the Laboratory of Neutron Physics continued to study fundamental properties of the neutron, parity violation effects arising in the interaction of slow neutrons with nuclei, various decay channels of neutron resonances, the mechanism for the neutron nucleus interaction. Experiments were performed both on the high efficient time-of-flight spectrometer at the IBR-30 booster, JINR, and on neutron sources of the other research centers (PNPI, Gatchina, USSR; Los Alamos Laboratory, USA).

In the period reported in the Laboratory there have been accomplished measurements of the lifetime of ultracold neutrons in a gravitational trap. A team of LNP (Dubna) and PNPI (Gatchina) scientists has succeeded in suppressing significantly UCN losses during their storage in a trap and came up to the direct observation of the neutron decay exponent. The original procedure has allowed them to obtain the most precise for the present value for the neutron lifetime τ_n=888.4 sec and the corresponding to it value of the axial to vector component ratio of 1.2677±0.0025.

Modern estimates of the scattering amplitude of neutrons on electrons and of the polarizability of the neutron on its interaction with heavy nuclei (lead, bismuth) were analysed. It was concluded that the difference in these estimates made by Dubna and Jülich groups and in derived from them neutron mean square charge radius values: (+0.12(2) fm and −0.11(2) fm), is due to different mathematical approaches used to interprete the data. In particular, corrections for the imaginary part of the scattering length appear to be of significance in the extraction of the neutron polarizability coefficient from the neutron scattering cross section data.

The POLYANA instrument for resonance neutron polarization has been reconstructed to give a tenfold increase of efficiency. The search for parity violation effects in p-wave resonances continued. The resonances E_o=9.6 eV (Rb) and E_o = 7.0 eV, E_o = 21.9 eV (^{113}Cd) were investigated. Parity violation has been detected only in the resonance E_o= 7 eV ^{113}Cd: $p = (-9.8\pm3.0)\times10^{-3}$. The sign of the effect is of interest. It confirms the regularity of the effect behavior in various nuclei. This fact speaks in favour of the validity of the modern point of view on the mechanism for parity violation.

LNP-PNPI joint experiments continued on the observation of parity violation effects for few-nucleon systems in (n, p) and (n, α) reactions. These experiments have the aim to identify contributions of charged and neutral weak currents and to have estimated weak interaction constants. An upper estimate of $(-6.4\pm5.5)\times10^{-8}$ obtained for the ^{6}Li(n, α)^{3}H reaction is essentially lower in comparison with earlier estimates and with the theoretical estimate derived in the framework of the cluster model of ^{7}Li.

LNP scientists participated in the preparation of instrumentation for and in carrying out experiments on the LANSCE spectrometer (Los Alamos, USA) to study parity violation in radiative capture of polarized resonance neutrons. The latest value for parity violation effect in lanthanum has been confirmed and the new value of $(1.1\pm0.2)\times10^{-2}$ obtained for the resonance ^{117}Sn(n, α) E_o=1.33 eV. For resonances E_o = 26.4 eV, 34.0 eV there have been obtained only upper estimates of the effect.

Accomplishments in the measuring procedure development have permitted significant background suppression in experiments on the study of population of states at energies larger than 1 MeV in the gamma-decay of compound states of heavy nuclei. The new method has been developed for the construction of complex level schemes of heavy compound nuclei decay on the basis of the (n, α) and (n, 2α) data. This method allows one to construct decay schemes of complex nuclei up to excitation energies of 3–4 MeV at the nowadays best level of confidence. At that unambiguous identification of transition and level multiplets takes place.

Lower (but near to real) estimates on the total radiative strength function (RSF) were obtained for primary (E1+M1) gamma-transitions with energies above 0.5 MeV to show that:

- RSF's are better described in the framework of the model for the giant electric dipole resonance with the width Γ_G dependent on the temperature of the final state of nucleus and the energy of γ-quanta (as suggested by LNP and Voronezh State University theorists), than in the framework of the generally accepted model assuming the width Γ_G to be constant.

- To describe the RSF energy dependence one has to take into account enhanced γ-transitions between single particle 4S-3P neutron shells, whose contribution is very large. Gamma-multiplicity fluctuations in some resonances of ^{147}Sm in the energy range from 15 to 900 eV were measured using the NaJ(Tl) based 4π-detector of γ-quanta. Distinct correlation between the resonance multiplicity spectrum and resonance spin was observed to help spin assignments to 90 resonances.

Investigations of the scattering of 1–300 keV neutrons from gaseous samples of krypton and xenon have provided data on the neutron strength functions $S^1_{1/2}$ and $S^1_{3/2}$ and contributions of far-lying levels R^∞_0 and R^∞_1. In krypton experiments there has been refined the behaviour of the R_1(A) curve at A=70–90 showing an anomalous sign of the neutron p-wave phase shift.

Experiments continued on the study of (n,p) and (n,α) reactions on stable and radioactive nuclei. LNP scientists in cooperation with a group from the Institute for Nuclear Research of the Ukranian Academy of Sciences have measured thermal neutron cross sections on rare isotopes,^{36}Ar(n,α)^{33}S and ^{50}V(n,p)^{50}Ti.

The collaboration with Peking University scientists has yielded the experimental procedure and test measurements of charged particle spectra from reactions with fast neutrons resulting in the improvement of the multisection ionization chamber capable of energy and range of particles analysis.

Fission scientists investigated yields of certain fragments in certain ^{239}Pu resonances from 0.2 eV to 230 eV by measuring characteristic γ-transitions of fission fragments. A peculiarity in the mass dependence of relative fission fragments yields in resonances has been observed to be in antiphase with the analogous dependence from ^{235}U experiments by Hambsch et al.

Average parameters of fission γ-quanta multiplicities were calculated by weighing to be n_γ=7.26±0.19, E_{tot}=6.68±0.12 MeV and the average energy E_γ=0.98±0.03 MeV.

Model estimates of fission characteristics of ^{235}U and ^{239}U in the low energy range were analysed. For the average characteristics of the (n, γ, f) process there have been obtained the following values: ^{235}U resonances with $J^\pi = 4^-$:

$$\overline{\Gamma}_{\gamma f}\overline{N}_{\gamma f} = (0.42 \pm 0.10) meV,$$

$$\overline{\Gamma}_{\gamma f}\overline{E}_{\gamma f} = (410 \pm 120) eV^2$$

^{239}Pu resonances with $J^{\pi} = 1^{+}$:

$$\overline{\Gamma}_{\gamma f}\overline{N}_{\gamma f} = (1.5 \pm 0.5) meV,$$

$$\overline{\Gamma}_{\gamma f}\overline{E}_{\gamma f} = (2150 \pm 650) eV^2$$

It is shown that experimentally observed fluctuations of characteristics of total fission in 4^- resonances of ^{235}Pu can be explained in the framework of the multimode fission model taking into account the (n, γf) process.

At the Laboratory there are going construction works on the UGRA instrument for the determination of the neutron polarizability coefficient, (α_n) by high precision measurements of angular distributions of neutrons scattered on heavy nuclei. An error in measured relative asymmetry of forward-backward scattering must not exceed the value of $(2\text{–}3)\times10^{-4}$ to reduce the error in α_n down to 3×10^{-43}cm^3. This instrument can be also used for:

- the search of light scalar particles, the interaction carriers;
- the search for and investigation of mixed (s+d) resonances;
- the determination of spin channels mixtures in p-wave resonances;
- the nondestructive quantitative analysis of samples for hydrogen present in them.

The new chopper-monochromator for cold neutrons based on small angle neutron scattering alteration by means of magnetized/demagnetized foils has been proposed. An "inelastic" adiabatic spin-flipper version has been developed for the case of cold neutrons.