ISINN-4
IV International Seminar
on Interaction of Neutrons with Nuclei

Neutron Spectroscopy,
Nuclear Structure,
Related Topics

Dubna, 1996 Abstracts
JOINT INSTITUTE FOR NUCLEAR RESEARCH

E3-96-114

IV International Seminar
on Interaction of Neutrons with Nuclei

NEUTRON SPECTROSCOPY,
NUCLEAR STRUCTURE,
RELATED TOPICS

Dubna, April 27—30, 1996

Abstracts

Dubna 1996
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### ISINN-4 Preliminary program

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Nuclear Structure at Low and High Excitations

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Vibrational states at low and high excitation energy and gamma-ray transition rates from the ground to excited states and between excited states in deformed nuclei in the rare-earth and actinide regions have been calculated within the quasiparticle-phonon nuclear model with the wave functions consisting of one- and two-phonon terms. The influence of the fragmentation of one-phonon states on the E1 and M1 strength distribution has been studied. It was shown that this fragmentation strongly affected at excitation energies above 2.5 MeV. The calculated fragmentation of the E1 and M1 strengths in odd-mass nuclei is much stronger in comparison with that in doubly even deformed nuclei.

Gamma-ray transition rates between one-phonon terms of the wave functions of the initial and final states are small and very fluctuative. There are fast E1 and M1 transition with energy around 2.5 MeV between relatively large many-phonon components of wave functions of the initial and final states differing by the octupole with \( K^* = 0^- \) or 1\(^-\) or quadrupole with \( K^* = 1^- \) phonon. The strong 2.5 MeV peak has been observed in the first-generation gamma-ray spectra in the two-step cascades following thermal-neutron capture and in the \(^{160}\text{Dy}(^3\text{He},\alpha)\) reaction at several excited energies. These experimental data indicate relatively large many-phonon components in the nuclear wave functions in the excitation region up to 8 MeV. Therefore, one may expect that the order take place up to excitation energy 5–8 MeV.
DESCRIPTION OF NEUTRON AND GAMMA-RAY WIDTHS
OF HIGH EXCITED STATES OF SPHERICAL NUCLEI
IN THE QUASIPARTICLE-PHONON NUCLEAR MODEL

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The fine structure of high excited nuclear states is needed for explanation of the specific
features of neutron and gamma-ray interaction with atomic nuclei. Neutron and gamma-ray
widths are basic decay characteristics of these high excited nuclear states and knowledge
of their energy dependence allow to describe carefully different decay channels. Usually
the statistical model is used for their simulation.

Last works show that use of the quasiparticle-phonon nuclear model (QPNM) permits
to achieve quality right description of the photoabsorption cross-section structure and of
the neutron and gamma-ray strength function behaviour /1,2/. In this work we investigate
the structure and the energy dependence of neutron and gamma-ray widths of Zr-92 in
the framework of the QPNM. The use of this method leads to better understanding of the
decay properties of high excited nuclei.

1. Belyaev S.N., Vasiliev O.V., Voronov V.V. et al., Proc. of 3 Intern. Seminar on
2. Blokhin A.I., Storozhenko A.N., Proc. of 3 Intern. Seminar on Interaction of
An interesting phenomenon of "trapping" occurring in a system of resonance states interacting with each other via the continuum had been studied now for more than a decade (see e.g. [1],[2]). However the questions of whether this phenomenon is typical for real nuclear systems and what are its experimental "signatures" remain open as yet.

We start investigating these questions in case of resonance states for medium and heavy nuclei where the statistical approach has proved its validity. As a starting point we use the results of [3], where it was shown analytically that in the one-channel case the onset of trapping occurs when the ratio of average resonance widths $\langle \Gamma \rangle$ to average resonance spacing $D$ reaches the critical value $2/\pi$. In order to apply this criterion to the realistic nuclear case we had first to generalize the approach of [3] for the case of $N$ channels whose partial widths $\langle \Gamma_n \rangle$ contribute approximately equally to the total resonance width $\langle \Gamma_{tot} \rangle \approx N \langle \Gamma^n \rangle$. We show that the above critical condition in this case can be generalized to

$$\frac{\langle \Gamma^n \rangle}{D} = \frac{2N}{(N-K)\pi} \approx 1. \quad (1)$$

Here $N$ is the number of coupled resonances ($N \gg K$).

Further on we applied the methods of Mahaux-Weidenmueller theory [4] together with R-matrix approach in order to get the analytic estimate for nucleon channels:

$$\frac{\langle \Gamma^n \rangle}{D} \approx \frac{4W(E)\Gamma_0(E)}{D_0^2}. \quad (2)$$
Here $W(E)$ is the imaginary part of the optical model potential, while $\Gamma_0(E)$ and $D_0$ are the single-particle resonance width and spacing, correspondingly. Combining eqs.(1) and (2) with the dependences of $W$, $\Gamma_0$ and $D_0$ on incident neutron energy $E$ and atomic number $A$, we obtain an expression for the value $E_{\text{crit}}$ which defines the onset of trapping phenomena in each region of target nuclei $A$. The greatest ambiguity in numerical estimates of $E_{\text{crit}}$ comes from the lack of precise information on the $E$-dependence of $\Gamma_0$. The most conservative estimates can be obtained for s-wave neutrons whose $\Gamma_0$ has the slowest increase with $E$. Those conservative estimates show, for example, that for $A \approx 150$ resonance trapping starts at $E_{\text{crit}} \approx 30$ MeV.

References

In comparison with deformed nuclei, the progress in the understanding of vibrational nuclei has been far slower. Recently [1] a method for the identification of multiphonon states was successfully developed. The global nuclear properties (such as the level energies) being less strongly perturbed by the presence of additional structures than the local properties (like the wave functions and the transitions probabilities), an examination of the excitation patterns provide an adequate filter to select "good" or potentially good vibrational nuclei. A survey was performed [2] and it was found, surprisingly, that the energies of the first $2^+$ states are systematically small by about 15% with respect to the values expected from the global nuclear properties [2, 3]. This appears to be in contradiction with the general belief that these states have a high purity. It can be questioned whether such results are not simply an artifact due to the weights used in the fits. One way to answer this question is to compare the experimental results with the predictions of the Brink model [4]. The formula for 4 and 5 phonons were thus explicitly calculated. It will be shown that the predictions are quite good, provided the 1 phonon energy is renormalized, i.e. increased by about 15%. Since the Brink method does not involve any fit, a problem of weights cannot be invoked. Alternative explanations will be presented.

The yield of photoneutrons is measured with step ~ 100 keV in $^{181}$Ta and $^{209}$Bi by using the bremsstrahlung with the endpoint energy in the range 6–17.3 MeV. The experimental data for reactions on the nucleus $^{209}$Bi has been obtained with step ~ 48 keV in the energy interval from the reaction threshold to 8.6 MeV. The relative error for measured yields at 17 MeV is about ~ 0.07%. Experimental conditions enable one to resolve substructures with widths ~ 200 keV near a threshold and with widths ~ 0.5–1.5 MeV in the region of the GDR maximum. $\sigma(\gamma,n)$ cross section in $^{209}$Bi reveals a few well resolved peaks in the low-energy tail of giant dipole resonance and a substructure at the maximum of the resonance at 17 MeV. Peaks positions and amplitudes are compared with corresponding peaks in $^{208}$Pb obtained in previous measurements and from theoretical predictions. It is concluded that core excitation plays an important role in photoexcitation of giant dipole resonance in $^{209}$Bi.

This work was supported in part by a grant № 95-02-03812 from RFBS.
The experimental data on the magnitude and the energy dependence (within the interval about $2-3\,\text{MeV}$) of the M1 photon strength function (M1-PSF) are available now for some nuclei. The energy of maximum and total width of the M1 giant resonance have been deduced from the data for $^{106}\text{Pd}$ [1] and $^{114}\text{Cd}$ [2].

In the presented work the semimicroscopical approach used previously in ref.[3] is applied to calculate M1-PSF. The approach is based on: (i) consideration of relevant particle-hole states within the RPA with a taking into account nucleon pairing; (ii) phenomenological description of the coupling of the mentioned states to manyquasiparticle configurations. The spreading width of each $1^+$ particle-hole state is supposed to be equal to sum of corresponding particle- and hole-state widths. This supposition seems to be correct in view of small collectivization of the $1^+$ states due to particle-hole interaction. Parametrisation of the quasiparticle spreading width is choosen to be the same as in the calculations of total radiative width of neutron resonances [4]. Thus, no free parameters are used for calculation of the M1-PSF.

Calculated results are compared with corresponding experimental data.

References


ON THE DIRECT NEUTRON DECAY OF SUBBARRIER SINGLE-NEUTRON STATES IN NEAR-MAGIC NUCLEI

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After intensive experimental [1] and theoretical [1, 2] studies on spreading of high-energy single-quasiparticle states in medium-heavy nuclei, the main interest is shifted now to investigation of decays of these states. The experimental data on the direct neutron decay of high-spin subbarrier single-neutron states in $^{91}\text{Zr}$ and $^{209}\text{Pb}$ populated in the $(\alpha, ^3\text{He})$ reaction have been reported in [3, 4].

Recently an approach is proposed to describe the branching ratios for the direct nucleon decay of subbarrier single-nucleon states in near-magic nuclei to the ground and low-excited (one-phonon) states of the product nucleus [5]. The approach is based on the use of an optical model and the simplest version of the coupled-channel approach (CCA). Thus, the single-particle continuum is taken into consideration exactly.

In the presented work we: (i) extended the calculations performed in [5] to the case of the direct neutron decay to the $2^+$, $4^+$, $6^+$, $8^+$ one-phonon states in $^{90}\text{Zr}$; (ii) compared the branching ratios for the decay to the first $3^-$ state in $^{90}\text{Zr}$ and $^{208}\text{Pb}$ calculated with the use of phenomenological and microscopical transition potentials for the $3^-$-phonon; (iii) checked the possibility to use the perturbation theory on the transition potential in the CCA calculations.

The calculation results are compared with branching ratios deduced from corresponding experimental data [4].

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The neutron optical potential with fragmentation and retardation effects

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The connection of the neutron optical potential with shell-model and Hartree-Fock potentials in the scheme of generalized Fermi-liquid theory. The calculation of the real part of neutron optical potential on the base of realistic nucleon-nucleon forces. New symmetries. The role of gradient term and the surface absorption of neutron. The dispersion relations for neutron optical potential. The generalization of the theoretical scheme on the case of optical potentials of compound particles.
For the calculation of the mentioned quantities the semi-microscopic method that we have suggested before is used \cite{1}. It is based on a successive microscopic calculation in the framework of the Green function method of the self-energy operator parts that contains collective low-lying "doorway" states and also on the parameterization of the remaining part of the self-energy operator that turned out to be rather small for the neutrons with the energy lower than 10-12 MeV.

It is very interesting to analyse the value of the role of the enrichment of the "doorway" states spectors conditioned by two physical reasons: 1) pairing in nuclei and, consequently, appearing additional (compared with magic nuclei) collective low-lying phonons, 2) the fragmentation of the "doorway" states in "hot" nuclei.

The calculations were made for $^{208}$Pb and $^{204}$Pb at finite and zero temperature. The imaginary part of the optical potential for neutrons with energy up to 10 MeV has been calculated in "hot" nuclei. The influence of the mentioned enrichment of the "doorway" states spectors on the imaginary part of the optical potential and the absorption cross section of the neutrons are studied. The fields of a noticeable influence of this enrichment are discussed.

STUDY OF SENSITIVITY OF ISOMERIC RATIO TO PARITY DEPENDENCE OF NUCLEAR LEVEL DENSITY

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The work is devoted to analysis of experimental data on isomeric ratios (IR) of $^{44m}$Sc $^{[1]}$, $^{73m}$Sc $^{[2]}$, $^{137m}$Ce $^{[3]}$, and $^{198m}$Tl $^{[4]}$, produced in $(\alpha, x\nu\gamma)$ - reactions in the incident energy range from 10 to 40 MeV. The analysis is carried out in the frame of Hauser - Feshbach formalism taking into account pre-equilibrium processes by exciton model. The competitive emission of neutrons, protons, $\alpha$ - particles, and $\gamma$ - quanta is regarded. Sensitivity of IR value to variation of parity dependence of the level densities in the excitation energy range up to 5 MeV is studied. It is shown, that the set of experimental data both on IR and secondary particle spectra in the reactions with light nuclei ($A < 70$) allows the obtaining of information on the parity dependence of nuclear level density.

Phenomenological description of neutron resonance level densities

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The paper presents a function describing the dependence of neutron resonance density $\rho$ upon the neutron number $N$ in target nucleus. It has been obtained from the analysis of experimental values for 284 nuclides. The achieved agreement of values from the proposed description and experimental data is of one order of magnitude. The function $\rho_{\text{calc}}$ adequately describes general tendency and shell model effects observed in the experimental dependence of $\rho_{\text{exp}}$ upon $N$.

![Graph showing comparison of normalized and spin reduced experimental and calculated values of neutron resonance level densities.]

Fig. 1
Comparison of normalized and spin reduced experimental and calculated values of neutron resonance level densities.
Double-differential neutron emission cross-sections in \((p,n)\) reaction on \(^{208}\text{Pb}\) and \(^{209}\text{Bi}\) have been measured at proton energy of 7 MeV and 11 MeV. The measurements have been performed by time-of-flight method with the resolution 1 ns/m at a path length 2.5 m. Neutrons were detected by the scintillation detector on the base stilbene crystal with identification of neutrons and gamma-rays on the principle of separate integrating of signal components. The neutron detector efficiency has been determined by measuring of the standard \(^{252}\text{Cf}\) fission neutron spectrum.

The analysis of the data by means of Hauser-Feshbach calculations with relations of the back-shifted Fermi gas model and the generalized superfluid model of nucleus for nuclear level density have been performed. The absolute level density of \(^{208}\text{Bi}\) and \(^{209}\text{Po}\) and model level density parameters have been determined. The results of comparison with available systematics of nuclear level density parameters are discussed.
Recently a maximum in the cross section for the reaction \( H(\alpha, d) \) has been observed [1]. It was interpreted as an excited state of the \(^3H\) nucleus with an energy \( E' = 7.0 \pm 0.3 \) MeV and width \( \Gamma' = 0.6 \pm 0.3 \) MeV. The energy \( E' \) lies about 0.7 MeV above the threshold \( (E_h = 6.26 \) MeV) for the breakup of the \(^3H\) nucleus into a neutron and a deuteron. While the width \( \Gamma' \) is too large for isospin forbidden transition \( T = 3/2 \rightarrow T = 1/2 \). So the question arises: why such excited state of the \(^3H\) nucleus, if it really exists, is not seen in the elastic cross section of \( n - d \) scattering?

We have advanced a hypothesis [2] that an excited state of \(^3H\) nucleus has a spin and parity of \( 1/2^+ \) and the same configuration as the \(^6He\) ground state. It was shown that a resonance due to the excited state may not be seen in the doublet channel of the elastic \( n - d \) interaction because of a destructive interference of the phase shifts of the potential and resonance scattering. In the framework of the hypothesis the amplitude for an electromagnetic transition to the ground state of the triton is strongly suppressed. Therefore the excited state cannot be observed in radiative capture of neutrons by deuterons.

Nevertheless the excited state should manifest itself in small irregularities of elastic cross section of \( n - d \) scattering near the energy \( \sim 0.1 \) MeV. These irregularities may be strengthened along with partial cross section of doublet channel scattering and 

\[ \text{(1) D.V.Aleksandrov et al., JETP Lett., 1994, v.59, p.320.} \]
\[ \text{(2) A.L.Barabanov, JETP Lett., 1995, v.61, p.7.} \]
INFLUENCE OF TARGET-NUCLEI CHARACTERISTICS
ON ISOMER CROSS SECTIONS

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The theoretical model of isomer cross-sections calculation, based on gamma-cascade model, describes available experimental data for ground state targets reasonably good. The results of systematic investigations of an influence of target nuclei (20 ≤ A ≤ 210) characteristics on isomer production cross sections are discussed. It is shown that isomer cross sections for targets in excited states may differ from the same values for ground state targets. In radiative capture of neutrons cross-sections of isomers with outstanding characteristics (\(^{53m}\)Fe, \(^{91m}\)Zr, \(^{177m}\)Lu, \(^{177m,178m,179m}\)Hf) will change so, that it is possible to say about closing or opening of corresponding channel of reaction at transition from ground to isomer state of targets. This effect is caused by law of conservation of total angular momentum. The main feature of inelastic scattering of resonance neutrons on targets in isomer state is absence of reaction threshold.

The analysis of isomer production cross-sections in (n,2n), (n,p) and (n,α) reactions shows, that the considerable changes of corresponding cross-sections for isomer targets are expected, in spite of the fact that the summary reaction cross-sections should vary slightly for neutron energies far from reaction thresholds.

The relationship between spin of target and spin of residual nuclei isomer is the main factor of isomer cross-section change: as the absolute value of spin difference increases isomer cross-section decreases, as a rule; and at reduction of spin difference - cross-section increases. The additional factor affecting isomer cross-section is the energy of initial excitation of targets.
NUCLEAR SHELL STABILIZATION OF EXCITATIONS AND NUCLEON SEPARATION ENERGIES

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Three relatively simple and transparent methods of data analysis were used in the study of quantitative values of the parameters of nucleon-nucleon interactions in few-nucleon systems. The first method is based on the assumption that mean values of the residual n-p interactions might be estimated from resultant effects in the total binding energies and by counting of the number of interacting pairs. Results for light nuclei were described in [1]. As application of this method the values of parameters of residual nucleon interaction on different shells were calculated from the differences of nucleon separation energies. In [2] effect of their stability was shown by the clearly seen linear dependence of the values of valence nucleon (Z=29,51 and 83) separation energies. The discrepancy of these stabilized values will be discussed. These effects are compared with near constance of the values of one neutron and two protons separation energies in the region of the closing of major shells N=8,20,82,126.

The values of the parameters derived by this method are compared with the values of stable excitations of some near-magic nuclei and proximate to them stable intervals (parameters of nonstatistical effects) in middle part of excitation spectra of the neighboring nuclei. Some values of stable intervals at higher excitations which are seen as nonstatistical effects in spacing distribution of neutron resonances are found to be in quantitative relation with some of derived parameters. These two methods based on independent data files has given practically the same values of the parameters of residual interaction. The possible reason of the long-range correlations in the values which are usually described by the mean field approximation will be discussed.

The third method of data analysis is using observed integer relations in the values of stable intervals in nuclear excitations and effect of long-range correlations in nucleon separation energies of near-magic nuclei in attempt to describe by the same set of the parameters the values of total binding energies of many nuclei.

General character and possible fundamental meaning of the observed effects is discussed in the connection with observed in data manifestation of the values close to the binding energies of deuteron (2224 keV and related to one nucleon values of stable energy intervals D=1112-1107 keV observed in some odd-odd nuclei with Z=20-29).

UNIFIED APPROACH TO THE MULTILEVEL PARAMETRIZATION OF RESONANCE CROSS SECTIONS

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The practical schemes for calculations of resonance neutron cross sections have been developed on the base of different approaches to the $R$-matrix reaction theory. This is useful for working with ENDF/B — VI data files for purpose of reactor design and nuclear safety calculations. Method for calculation and analysis of neutron cross sections and their functionals was put into practice in the resolved resonance region making use of ENDF/B format.

Methods for transformation of $R$-matrix resonance parameters into $S$-matrix Kapur-Peierls and Adler-Adler parameters were realized.

A new formalism in the resonance reaction theory was developed. This exact "combined" formalism with constant complex parameters is a generalization of the Reich-Moore formalism. An exact method for transformation of $R$-matrix parameters into parameters of combined formalism was realized. All methods and formalisms are available in program codes developed.

In the unresolved resonance region a new procedure for calculation of the average cross sections and their functionals has been developed on the base of the characteristic function $\mathcal{F}$ of the statistical Wigner’s $R$-matrix. Investigations of the $\mathcal{F}$ function have been done for the case of one channel scattering in competition with multichannel radiative capture, which corresponds to resonance cross sections for non fissible nuclei. The average cross sections and self-shielding factors for $^{238}\text{U}$ are calculated and compared with results obtained experimentally and calculated by other methods.
SOME ASPECTS OF THE ANALYSIS OF PARITY VIOLATION EFFECTS OBSERVED AT NEUTRON P-WAVE RESONANCES

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Parity Violation (PV) effects have been observed in Los Alamos (USA) at many p-wave resonances in the transmission of polarized neutrons through several targets of unpolarized isotopes. The statistical nature of the neutron-nucleus reaction and the fairly large number of observed PV-effects make it possible to extract the root-mean-square matrix element, $M$, for each target isotope using the maximum likelihood method. In the case of spin-zero target nuclei the analysis is straightforward. A bias in the estimate of $M$ may occur if the number of resonances for a target isotope is rather small. There are ways to remove such a bias at least approximately, using i) a theoretical approach based on the knowledge of the probability density function, ii) Monte-Carlo simulations, and iii) the so-called jack-knife method by Quenouille.

To analyse PV-effects observed with non-zero-spin target nuclei properly, it is necessary to know at least the spins of the s-wave and p-wave resonances. Neutron capture gamma-ray spectroscopy is carried out at the GELINA facility in Geel (Belgium) to assign spin values to s- and p-wave resonances. In addition it is important to know the $\pi/2$-amplitudes at the neutron entrance channels. Several types of experiments can be done to obtain these $\pi/2$-amplitudes, notably transmission of polarized neutrons through targets of polarized nuclei and angular distributions of gamma-ray transitions. The latter can be carried out at Geel with modest changes of the experimental facility implemented.

PV-experiments have been carried out in two mass regions, first at $A=230$ and recently at $A=110$ using zero-spin and non-zero-spin target nuclei. It is expected that the analysis of the latter experiments will produce values of $M$ with similar accuracy as for the $A=230$ region, assuming that the above-mentioned additional information becomes available.
PARITY VIOLATION IN NEUTRON TRANSMISSION THROUGH XENON


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A large parity violating longitudinal analyzing power has been discovered in polarized neutron transmission through xenon. A parity-violating analyzing power of 4.3 ± 0.2% was observed in a newly discovered neutron resonance at 3.2 eV. The measurement was performed with a liquid Xe target of natural isotopic abundance at the Los Alamos Neutron Science Center. This beamline was constructed by the TRIPLE collaboration, and has been used for studies of parity symmetry in the compound nuclear system[1]. The experiment was motivated in part because substantial quantities of highly-polarized, solid $^{129}$Xe can now be produced in principle[2].

Polarized targets are required to search for a P-odd T-odd term in the forward coherent scattering amplitude for low energy neutrons of the form $D\hat{s} \cdot (\vec{k} \times \vec{I})$ where $\hat{s}$ is the neutron spin, $\vec{I}$ is the target spin, and $\vec{k}$ the neutron momentum. Depending on the isotope responsible for this resonance, it may be possible to design a sensitive test of time reversal invariance using a polarized-Xe target, a polarized epithermal neutron beam and the large longitudinal analyzing power of the resonance. The Xe isotope responsible for this resonance has not yet been identified.


According /1,2/ the T-noninvariant effect of spin rotation arises under thermal neutron dynamical diffraction by crystals with nonpolarized nuclei. This effect is determined by coherent elastic scattering amplitude at a non-zero angle. In the present message it is shown that it is possible to investigate the effects of T-noninvariant spin rotation and spin dichroism in crystals even in case when diffraction conditions are not fulfilled. As a consequence the possibility of investigation T-noninvariant spin rotation and spin dichroism which is determined by coherent elastic scattering amplitude at a non-zero angle in the range of epithermal neutrons arises /3/.

The isotopic identification of the parity-violating neutron p-wave resonance at energy $E_p = 3.2$ eV in Xe

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ABSTRACT

Two dimensional pulse height - TOF (time - of - flight) spectra were measured to make the isotopic identification of the parity-violating p-wave resonance $E_p = 3.2$ eV recently observed in Xe. Analysis of TOF spectra corresponding to the characteristic low energy gamma-rays established the $^{131}$Xe isotope as the origin of 3.2 eV resonance. New findings pose a challenge for developing a polarized solid $^{131}$Xe - target for a test of time-reversal invariance with neutrons.

A large parity non-conserving (PNC) effect was observed recently for the p-wave neutron resonance $E_p = 3.2$ eV in Xe. This widens perspectives for the study of time-reversal invariance with polarized neutrons by searching for the term in the neutron forward scattering amplitude proportional to $\hat{S}_n \left[ \hat{T} \times \hat{M} \right]$. Such transmission type experiments require fairly large polarized targets. Till now only one nuclear target a dynamically polarized lanthanum compounds - has been developed by KEK group for these experiments. With advent of the P-violating low energy resonance in Xe, the laser-polarized solid Xe - target might be another and, in a way, more optimal choice due to the advantage of the modest magnetic field and ease of maintenance. One have to know, however, which of Xenon isotopes is the origin of the 3.2 eV resonance. The Los Alamos PNC experiments made with the Xe-natural and the $^{129}$Xe - targets indicated indirectly that the 3.2 eV resonance belongs, most probably, to the $^{131}$Xe isotope. This talk describes the measurements we made for the direct isotope assignment of the $E_p = 3.2$ eV p-wave resonance by the well established characteristic gamma-rays method which was used for an analogous purpose in a case of a p-wave resonance in bromine.

The experiment was carried out at a beamline of the IBR-30 pulsed neutron source of the Joint Institute for Nuclear Research, Dubna.

From results obtained, we conclude that the parity-violating p-wave resonance observed in Los Alamos experiment belongs to $^{131}$Xe isotope.

$^{131}$Xe and $^{129}$Xe nuclei have different spins ($I = 3/2$ and $I = 1/2$ respectively), this differentiate conditions for obtaining the corresponding polarized isotopic targets. The development of a frozen $^{131}$Xe polarized target of a mass more than 100 g appears to be a great challenge one have to accept to respond the needs of T-violation study with resonance neutrons.
New precise measurement of neutron life time

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Our previous neutron life time measurement (1993, [1]) has indicated that our method based on using ultracold neutron (UCN) storage at a very clean vessel with a "liquid" wall and with simultaneous detection of inelastically scattered neutrons provided recently the most precise result: 882.6±2.7 sec. The serious improvement of the previous experimental installation has been done to suppress the most of methodical impurities. New installation permits both a) to make change the frequency of UCN collisions by changing of the surface area of the storage vessel and b) to refresh the oil layer on the vessel wall without the vacuum break. Moreover the "a)" procedure was carried out automatically under computer control. It provided the change of experimental condition periodically many times during a run to exclude possible unstabilities from the final result.

By means of it the following independent data sets are obtained for each choice of the surface area of the storage vessel: \( \lambda_{tot} = \frac{\ln(N_f/N_i)}{t} \), \( \lambda_{ul} = \frac{\epsilon J \lambda_{tot}}{(N_f-N_i) \varepsilon_{th}} \), where \( \lambda_{tot} = \lambda + \lambda_{loss} \), \( \lambda \) is neutron \( \beta \)-decay probability, \( \lambda_{loss} = \lambda_{cap} + \lambda_{in} = \lambda_{ir}(1 + \frac{\sigma_{th}^U}{\sigma_{ir}}) = \lambda_{ir}(1 + \frac{\sigma_{th}^U}{\sigma_{ir}}) \), \( J \) is the count of heated UCN during the storage time interval \( t \), \( N_i \) and \( N_f \) are the registered UCNs at the beginning and at the end of the storage time interval correspondingly, \( \varepsilon \) is the registration efficiency of UCN accumulated in the bottle, \( \varepsilon_{th} \) is the registration efficiency of heated neutrons.

It combined to yield as a result:

\[
\lambda = \frac{\lambda_{tot}}{\varepsilon_{th}}, \quad \xi = \frac{\lambda_{loss}}{\lambda_{tot}} = \frac{\lambda_{cap} + \lambda_{in}}{\lambda_{tot}} = \frac{\epsilon J \lambda_{tot}}{(N_f-N_i) \varepsilon_{th}} / \frac{(N_f-N_i) \varepsilon_{th}}{(N_i-N_f) \varepsilon_{th}}.
\]

The achieved statistical precision of the neutron life time value \( \tau = 1/\lambda \) is about 0.8 sec while the \( \tau \) value will be evaluated with analysis of methodics inclusions and some test experiments. It is necessary to define the relative values of \( \varepsilon_{th} \), the velocity distribution of heated UCN for Fomblin oil layer at different used temperatures, the scattering cross section in Al and SS for heated UCN.

A MEASUREMENT OF THE CORRELATION COEFFICIENT A IN THE DECAY OF POLARIZED FREE NEUTRONS

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We have measured the β asymmetry coefficient A in the decay of free polarized neutrons. This coefficient is the angular correlation between the neutron spin and the electron momentum. From this quantity one deduces A = gA/gV which is a free parameter of the standard model of the electroweak interaction. First results on the β coefficient A will be presented on this seminar.

Over the last years it has become possible to deduce the weak interaction coupling constants gV and gA from neutron decay alone using the beta asymmetry coefficient A and the neutron lifetime. Consistency checks with other measurements allow several tests of the standard model: The law of the conserved vector current or the unitarity of the Kobayashi-Maskawa matrix can be checked. A disagreement would signal new physics beyond the standard model. Especially the possible implications of our measurements for right handed currents will be discussed. A second reason for these measurements is that all semileptonic weak interaction cross sections must be calculated with these neutron decay data as inputs. The measurement was made by using a loss free method of electron spectroscopy with the superconducting spectrometer PERKEO II. The neutrons were provided by the cold neutron beam at the beam position PF1 at the Institut Laue-Langevin in Grenoble. The data analysis will be finished in spring 1996. With PERKEO II we directly measure the β asymmetry by observing the difference in electron count rates as a function of electron energy for two opposite neutron polarization states. The neutrons are polarized with a supermirror polarizer and the neutron polarization is reversed with a current sheet spin flipper. We have measured the polarization and spin flip efficiency more accurately with a new technique. Neutrons pass through the spectrometer PERKEO II, whereas decay electrons are guided by the magnetic field to either one of two scintillation detectors with photomultiplier readout. The detector solid angle of acceptance is truly $2\times\pi$ above a threshold of 60 keV. Electron backscattering effects, which have been serious sources of systematic error in β spectroscopy, are effectively suppressed. An electron which backscatters from one detector is either reflected back or it will follow a magnetic field line and eventually hit the other detector. PERKEO II has a number of advantages over its predecessor PERKEO [1,2,3]. It uses a magnetic field perpendicular to the cold neutron beam created by a split pair configuration. As a consequence the electron detectors are installed far away from the neutron beam which reduced the background significantly. The signal to background ratio in the range of interest is 20 : 1. At the same time the electron magnetic mirror effect was mostly eliminated. In total about $2 \times 10^8$ decay electrons were detected.

Ref.
The Gamma Ray Induced Doppler broadening (GRID) technique is briefly reviewed. This method can be used for both, the study of lifetimes of nuclear states in the region below a few picoseconds, and the investigation of interatomic collisions at very low energies (some eV to some hundred eV). It is based on high resolution $\Delta E/E \approx 10^{-6}$ gamma ray spectroscopy and takes advantage of the simple fact that the energy of a $\gamma$ ray emitted from a nucleus which is moving, is shifted relative to a $\gamma$ ray emitted from a nucleus at rest. The recoil in GRID is induced by the electromagnetic decay of the nucleus of interest, produced by thermal neutron capture. The Doppler profile is essentially determined by the three parameters: the lifetime of the state under investigation, the velocity distribution of the excited nuclei at the moment of $\gamma$ emission, and the slowing-down process in the target. Be careful selection of the subjects for GRID measurements any one of these three may eventually be studied separately, leading to a wide variety of applications.
The standard abundance distribution of the elements in the universe is particularly well defined in the mass region of the lanthanides thanks to the chemical similarity of these elements. Therefore, the respective isotope patterns are reliably linked and provide an important basis for the investigation of several s–process branchings. New measurements of \((n,\gamma)\) cross sections are presented using the Karlsruhe \(4\pi\text{BaF}_2\) detector as well as the activation method. With these data several branchings between Ce and Lu could be substantially improved yielding a rather detailed characterisation of the helium burning plasma in red giant stars.
Re-Os CHRONOLOGY OF THE r-PROCESS NUCLEOSYNTHESIS TAKING INTO ACCOUNT ACCELERATED DECAY OF Re-187 AND NEUTRON CAPTURE IN EXCITED STATES OF Os-186,187 IN STAR CONDITIONS

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Two main sources of uncertainties of Re-Os chronology of the r-process nucleosynthesis were considered, namely accelerated decay of Re-187 and neutron capture from excited states of Os-186,187.

A new approach was used to estimate the contribution of the Re-187 accelerated decay based on analysis of abundances of the long-lived in earth conditions nuclei been pure products of the r- or the s-processes, namely Cd-113, In-115 and Lu-176, which lifetimes depend strongly on the matter temperature like Re-187.

To calculate the neutron capture cross sections of Os-186,187 in star conditions, a combine analysis of all existed experimental data on average total and partial neutron cross sections of these nuclei was carried out and their average neutron resonance parameters were determined.

Using of mentioned results the following values were estimated independently on supernova explosion dynamics:

- the upper and the lower limits of the r-process age as $T_r (\text{min,max}) = 3.4 \text{ and } 13.0 \text{ Gyr}$;

- the lower limits of the Galaxy and the Universe as $T_G, T_U (\text{min}) = 7.9 \text{ and } 8.9 \text{ Gyr}$.

The model-depended evaluation of the Galaxy age was obtained as $T_G(\text{mod}) = 13.1 (+1.7,-2.5) \text{ Gyr}$.
Exotic properties of light nuclei and their neutron capture cross sections

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Light neutron-rich nuclei may exhibit “exotic” nuclear structure properties, such as an extended neutron cloud (halo) or a relatively thick neutron layer (skin), outside the nuclear surface. These properties have been recently investigated by means of radioactive ion beam experiments which sensibly contributed to enlarge the nuclear structure picture of light nuclei toward the neutron drip-line.

We have recently investigated some implication of these results in one of the basic reaction processes: the \((n,\gamma)\) reaction. In particular, we have studied the influence of the neutron halo structure on the direct radiative capture (DRC) process [1,2]. This reaction mechanism may be responsible for the most part of the capture reaction rate in the particular condition in which the density of states is low enough to hinder the compound nucleus formation mechanism [3]. Furthermore, because the halo structure arises mainly from loosely bound s orbits, electric dipole \(\gamma\)-ray emissions can only be induced by incident p-wave neutrons. In fact, the p-wave DRC process in the neutron energy region of interest for nuclear astrophysics, is essentially determined by the El transition matrix elements \(Q_{\text{el}}^{(1)} = \langle \Psi_f | T^{\text{El}} | \Psi_i \rangle \). These matrix elements are, in turn, very much sensitive to the tail component (halo) of the final capturing state wave function \(\Psi_f\) and very little sensitive to the treatment of the incident neutron scattering channel state \(\Psi_i\) [2]. The energy dependence as well as the strength of El emission due to incident p-wave neutrons is therefore strongly influenced by the neutron halo structure of the residual nucleus capturing state. Whether this state is the ground or an excited nuclear state makes no difference in this scheme.

We have calculated several neutron capture cross sections of light nuclei using the DRC model. The calculations for \(^{12}\text{C}(n,\gamma)\) and \(^{16}\text{O}(n,\gamma)\) reactions have been compared with recent experimental results from direct measurements. At the same time, we have compared the \(^{10}\text{Be}(n,\gamma)^{11}\text{Be}\) DRC cross section with that derived from the experiment in the inverse kinematics (Coulomb dissociation of \(^{11}\text{Be}\)). These calculations enabled us to assess quantitatively the DRC model in terms of reliability and sensitivity to the (few) parameters involved. The DRC model has been then employed to predict capture cross sections relevant to important astrophysical processes.

Capture data for $^{108}$Pd taken at LANSCE in 1995 by the TRIPLE collaboration show an asymmetric shape for s-wave resonances. In particular, the TOF spectrum near the 33 eV resonance has a double-humped structure. A proposed explanation for this shape is the capture of neutrons after multiple scattering in the target. Incoming neutrons with energies higher than the resonance energy reach the target earlier than the resonance neutrons, are scattered, lose energy, and are captured as resonance neutrons. The effect is largest when the neutron width is large, and therefore is most pronounced for strong s-wave resonances. A computer code that simulates the experimental conditions using monte carlo techniques has been written. The target geometry and the beam characteristics are explicitly taken into account. Results of this test of the asymmetric shape of the resonances in the capture cross section of $^{108}$Pd will be presented.
ABOUT DETERMINATION OF POTENTIAL SCATTERING PARAMETERS IN THE LOW ENERGY REGION

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In a wide energy region the channel of neutron potential scattering gives a main contribution to neutron-nucleus interaction. This channel is characterized by so-called potential scattering parameters, which values are need to evaluate the neutron cross sections, as well as to determine other neutron parameters of nuclei.

The most reliable information on the potential scattering parameters can be obtained from analysis of the experimental data on neutron cross sections in the isolated resonance region. Beside of other sources of uncertainties, a main problem of such analysis is principal impossibility to account directly contributions of all resonances start from ground state up to continuum.

In the present work a consistent consideration of this problem is fulfilled. The influence of the number of resonances, taken into account from both sides of analyzed energy region, on the value of potential scattering parameter are investigated. The formula expressed this dependence is deduced. The results are confirmed by numerical simulated calculations.
THE RESONANCE PARAMETERS OF \(^{179}\text{Hf}\)

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The radiative capture and neutron elastic scattering cross sections for
\(^{179}\text{Hf}\) in the resonance energy region have been measured. The experiments
were performed on the IBR-30 time-of-flight neutron spectrometer in the
Neutron Physics Laboratory of JINR-Dubna. The \(4\pi\) multidetector system
Romashka has been used in the experiment. This system can register the
multiplicity of gamma-quanta emitted following the interaction of neutron
with nucleus.

The time-of-flight spectra corresponding to each multiplicity are ob-
tained in the experiment. In this presentation the new procedure for elabora-
tion of the experimental data is described. The area under the resonance
maxima in the spectra of radiative capture and neutron scattering are used
for determination of the resonance parameters of \(^{179}\text{Hf}\) and study the
statistical properties of those.

The investigation of the degree of freedom of the distribution law of the
radiation widths was performed. The distribution function is supposed
to be of \(\chi^2\) type with \(\nu\) degrees of freedom. The connection between \(\nu\)
and average multiplicity for each subsystem was studied. So we observed
the interaction between nuclear structure and the parameters of resonance
statistical distributions for this nucleus.
NUCLEAR PHASE TRANSITION - THE DISCOVERY AND EXPERIMENTAL STUDY POSSIBILITIES

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The data accumulated on the cascade $\gamma$-decay for 20 heavy nuclei [1] indicates that in addition to the enhancement of the two-step cascades with high-energy primary transitions, related to the level structures, the intensity of cascades with low-energy primary transitions cannot be described within the conventional statistical approach, either. Furthermore, this discrepancy is different for deformed, transitional and spherical nuclei. The enhancement of cascades with low-energy primary transitions clearly appears in deformed nuclei and it tends to disappear in nuclei with close to spherical shapes. Considering the heavy nucleus as a system of non-interacting Fermi-particles, no reasonable agreement with experimental data has been reached.

The observed dependence of the intensity distribution on the shape of the nucleus, as well as the appearance of enhanced equidistantly grouped levels and intensities, can indicate the possibly important role of collective excitations in the $\gamma$-decay of high-lying excited states. Assuming that the energy of the captured neutron passes partially to the excitation of quasiparticle states and partially to the excitation of the nucleus as a whole, one can consider the heavy nucleus as a system of interacting bosons and fermions and attempt to describe the nucleus properties using the well-studied thermodynamic quantities of superfluid macroscopic matter [2].

A new, simple model describing nuclear level density on the basis of superfluid nuclear liquids has been developed and the nuclear temperature has been re-determined. It was shown that the level density below a certain excitation energy is considerably less than the Fermi-gas model predictions and that the transition from superfluid to usual Fermi-gas can be introduced in order to improve the agreement between the experimental and the predicted model intensities of two-step cascades.

The experimentally obtained cascade intensities have been fitted within the modified Fermi-gas model and conventional $\gamma$-width energy scaling [3], and a reasonable agreement has been achieved for practically all of the investigated nuclei.

We can conclude: the properties of the $\gamma$-decay process of heavy nuclei below the excitation energy of some MeV are determined in considerable measure by the nuclear Bose-condensate, as well as by the phase transition between the Fermi- and Bose-systems formed by nucleons.

This work was supported by a grant N 95-02-03848 from RFRF.

Test of the E1 γ-ray strength function and level density models by the $^{155}$Gd (n,2γ)$^{156}$Gd reaction

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One of the main problems in the study of neutron radiation capture is evaluation of the radiative strength functions (RSF) for γ-transitions. The currently available experimental methods allow one to get such information mainly for the “hard” part of primary γ-transitions, for energies in the interval of $B_n - (B_n - 2)$ MeV, where $B_n$ is the neutron binding energy. For evaluation of RSF in the wide energy interval ($B_n - 0$), one needs to know the level density of the nucleus in the same excitation energy interval. This follows from the fact that the main quantities measured in the (n,γ) reaction: neutron capture cross section, total radiative widths, γ-transitions spectra are integral values that include the level density and RSF as underlying functions. On the other hand, if the RSFs are known one can extract information about the level density of nuclei. The main problem of (n,γ) spectrometry is to extract the level density of nuclei and the radiative strength functions of γ-transitions, individually.

In the present work, information about the level density of the $^{156}$Gd nucleus and strength functions of γ-transitions is extracted from two γ-cascade spectra of the $^{155}$Gd(n,2γ)$^{156}$Gd reaction. The method of statistically simulating of γ-cascade intensities has been used for this purpose. Two models are used for the E1-RSF calculations: the standard Lorentzian model and a model with an energy-dependent damping width and nonzero limit for $E_γ → 0$. As analysis shows, the cascade intensities calculated using the Fermi-gas model for the level density and the standard Lorentzian model for the E1-strength function are in good agreement with the experimental ones in the excitation energy interval up to $~ 3$ MeV. At the excitation energies above 3 MeV, it is necessary to make assumptions about the decrease in the experimental level density in comparison with the calculated one. A possible explanation of the observed effect is discussed.

This work was supported by a grant N 95-02-03848 from RFBR.
NEUTRON POLARIZABILITY HAS NOT BEEN DETERMINED.
HOW TO GET IT FROM $\sigma_{tot}$?
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Following [1], a detailed analysis of the method and results of [2] giving up to now the only meaning experimental value of the neutron electric polarizability $\alpha_n$ has been performed. This allows:

1) to see the definite physical sense of all coefficients of the fourth-degree polynomial in $k$ ($k$ is the neutron wave number), used in [2] to describe the scattering cross section $\sigma(k)$;

2) to find confirmation of the existance in the system $n + ^{208} \text{Pb}$ of the very strong, unknown s-wave resonance that was observed recently in the experiments [3];

3) to detect quantitatively the defect in method [2] of omitting the polynomial cubic in the $k$ term;

4) to detect quantitatively the wrong relation between the polynomial coefficients at $k^2$ and $k^4$ obtained in [2];

5) to propose the only way to get $\alpha_n$ from $\sigma(k)$: it is necessary to use both methods [2] and [3] but to complete the former with the cubic term and the latter with contribution of the $-1.91\ MeV$ negative resonance; it is necessary to reach the coincidence of both results.

References
Electromagnetic structure of neutron. Overview of modern dynamical models

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In view of the experiments planned in FLNP on n-e scattering amplitude estimations, a overview of some current theoretical studies on baryon electromagnetic structure is presented. A brief description of relevant dynamical models (cloudy bag model, Skyrme and Nambu-Jona-Lasinio models, color dielectric and others) is given and a compilation of recent numerical results for static properties of nucleons (mass, magnetic moment, r.m.s. charge radius) is made. Treating the neutron rms charge radius as a sum of the "intrinsic" one and of the Foldy term contribution, it is shown that no definite prediction for the "intrinsic" radius can be done. Even its sign cannot be established unambiguously from the models.

On the other hand, the dispersion of theoretical predictions for neutron r.m.s. charge radius doesn't allow us to make a choice between two groups of the experimental results. That is why the new, more precise experiments are desirable.
Determination of the Neutron Scattering Length of $^{207}$Pb by the Neutron Interferometry Method

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The coherent scattering length of $^{207}$Pb has been measured by means of the neutron interferometry method. The experiments were performed at the reactors of HMI (Berlin, Germany) and of NPI (Rez near Prague, Czech Republic). The value $b_c = 9.288(30)$ fm. was obtained.
RACTIONS WITH FAST NEUTRONS

ROLE OF COLLECTIVE EXCITATION IN THE CONTINUUM IN $^{93}$Nb(N,xN) REACTION

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The purpose of this contribution is to calculate the collective cross sections in the continuum and thus to give description of neutron emission from $^{93}$Nb at incident neutron energies of 14.0, 20.0, 25.7 MeV, that combines incoherently the three different preequilibrium reactions mechanism, namely the MSC reactions, the MSD reactions and the direct reactions that excite collective states including the giant resonances. The MSD and the preequilibrium MSC reaction cross section were calculated according to the FKK theory which has been modified in order to account for the gradual absorption of the projectile flux. In contrary to the original formulation of FKK the applicable MSD model was found to describe the incoherent quasiparticle excitation only. Therefore the MSD parametrization used in the calculation was taken from the fits to (p,xn) reaction cross sections that are free of strong isoscalar collective excitation. The coherent excitations that result in collective surface vibration of the nucleus are described by simple macroscopic model in the framework of DWBA. Absolute cross section for the excitation of collective levels were determined by using experimental deformation parameters and EWSR in case of giant resonances. The overall agreement between theory and experiment is very good even at the high outgoing energies where direct collective process dominate.
Measurements of the \((n, 2n)\) Reaction Cross-section Using the Time Intervals Spectroscopy Technique

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Abstract

Results of experimental investigations of the \((n, 2n)\) reaction cross-section for different nuclei are presented. Method is based on the measurement of the time interval between two correlated events - detection of the first and second emitted neutrons. Measurements were carried out on the INRNE neutron generator with an incoming neutron energy of 14.7 MeV. Neutron detector composed of 18 \(^3\)He proportional counters placed in a polyethylene moderator around a cylindrical central hole was used.

Results of the measurements of such nuclei as Cu, Co, etc., whose cross-sections are known with a precision better than 5% were used for the neutron detector response function calculation and neutron flux calibrations.

New results for the \(^{114}\)Cd and \(^{180}\)Hf cross-sections were obtained.
ANGULAR DISTRIBUTION AND CROSS SECTION OF THE $^{58}\text{Ni}(n,\alpha)^{55}\text{Fe}$ AND $^{54}\text{Fe}(n,\alpha)^{51}\text{Cr}$ REACTIONS AT 6 AND 7 MeV

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ABSTRACT

Energy spectra, angular distributions and cross sections of the (n,α) reaction for the $^{58}\text{Ni}$ and $^{54}\text{Fe}$ isotopes were measured at 6 and 7 MeV. Quasi-monoenergetic neutrons were produced via the D(d,n)$^3\text{He}$ reaction using a Van de Graaff accelerator. Alpha particles from the (n,α) reaction were detected using a parallel-plate grid-type twin ionization chamber. Neutron flux was determined with the help of a low mass fission chamber with enriched $^{238}\text{U}$ and a previously calibrated BF$_3$ long counter. Nearly symmetrical angular distributions, which are in agreement with the theoretical prediction of the statistical model, were observed. Our results of the (n,α) cross section are given in Table 1.

Table 1.

<table>
<thead>
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<th>Isotope</th>
<th>$E_n$ (MeV)</th>
<th>$\sigma_{nn}$ (mb)</th>
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<td>[1]</td>
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<td>6.0</td>
<td>75.0±7.5</td>
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<td>71±14</td>
<td>this work</td>
</tr>
<tr>
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<td>7.0</td>
<td>8.8±2.6</td>
<td>this work</td>
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</tbody>
</table>

REFERENCE

Detailed study of the double-differential cross-sections for $^{17}$O(n,α)$^{14}$C reaction

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ABSTRACT

$^{17}$O(n,α)$^{14}$C reaction has been studied in order to clarify discrepancies in the data on reaction cross-section in the range of 50 keV upto 1000 keV and to perform alpha-particles angular distributions corresponding to different resonances measurement. The experiment was carried out using gridded ionization chamber. The target was niobium oxide enriched in $^{17}$O.

The results of the experiment are in good agreement with the data of P.E.Koehler 1991 and show great difference between the cross-section measured and one deduced from the inverse reaction using the detailed equilibrium principal in the interresonance region.

The angular distributions measured are quite different from each other and represent all kinds of anisotropy: forward, backward, 90 degrees.

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Inelastic scattered neutron spectra for $^{238}\text{U}$ at incident neutron energies 313, 387, 474 and 578 keV were measured by the neutron time-of-flight spectrometer at the Institute of Physics and Power Engineering. The neutron TOF spectrometer is described in detail in [1,2]. Thin metallic lithium target was used as the neutron source.

Special attention was paid to increase the accuracy of the results. The experiment was simulated in detail by our Monte-Carlo code MULTIC, taking into account the interactions of proton beam inside the target, the reaction kinematics, the dimensions of neutron source, uranium sample and neutron detector, their mutual disposition and multiple neutron scattering in the sample. The special study was performed to investigate the properties of the neutron source in detail [3]. It was noticed that the background due to the neutron scattering on the sample environment should be taken into account in the final data processing.

The total inelastic scattering cross-sections for the first levels of $^{238}\text{U}$ were evaluated. The comparison of our results and ENDF/B-VI, BROND-2 and JENDL-3 evaluations is discussed.

ABSTRACT

The Lead Slow-down Time Neutron Spectrometer with a 65 ton lead pile and 14 MeV neutron pulsed generator has been built at the Nuclear Physics Department of Lodz University. Time dependent distribution of neutron density in the lead pile as well as resonance capture curves for some targets have been measured. The calibration curve for relationship between average energy of neutrons and their slowing-down time has been obtained (Fig. 1).

![Graph showing the relationship between slowing-down time and average neutron energy](attachment:image.png)

Fig. 1. Dependence of slowing-down time on average neutron energy
The TRIPLE collaboration uses a pulsed, polarized, high flux, epithermal neutron beam at the Los Alamos Neutron Science Center to study parity violation in the compound nucleus. The usual experiment measures the longitudinal asymmetry in neutron transmission through large samples of target material. Neutron capture provides an alternate method and enables measurements of parity violation with small amounts of isotopically pure target material. In 1995 TRIPLE commissioned a new neutron-capture detector consisting of 24 pure CsI scintillators. The individual scintillators are arranged in a cylindrical geometry around the beam pipe, provide a 3.3π solid angle and are shielded from scattered neutrons by 5 cm of 6Li-loaded polyethylene. The longitudinally polarized neutron beam is transported to the target by a 56 m solenoid. A Monte-Carlo code has been developed to calculate the degree of beam depolarization produced by gaps in the solenoid winding. Downstream from the capture-detector is a neutron polarimeter consisting of a 139La target and a 6Li-glass neutron detector. By measuring the known parity violation effect at the 0.73-eV resonance in 139La, the beam polarization can be extracted. The performance of this system will be discussed.
The high intensity neutron spectrometer developed on the base of Kurchatov Institute FAKEL linac in 1995 has been described. The neutrons are emitted from the uranium target displaced in the straight electron beam. The maximum average power of the electron beam is about 15 kw. The flight path is 5-8 m. The first measurements demonstrated that new spectrometer makes it possible to obtain new quality information.
A spallation source, called SINQ, is in construction at the Paul Scherrer Institute (PSI) in Villigen, Switzerland. A 1 mA, 590 MeV proton beam will hit a heavy target placed in the middle of a heavy water moderator tank. The thermal flux, close to the target will be about $2 \cdot 10^{14}$ n/cm$^2$s under optimal conditions. From a cold D$_2$ moderator neutrons will diffuse in two channels and a bundle of 7 neutrons guides. The PGAA system will be located at the end of a half-guide of section $2 \times 5$ cm$^2$. The expected flux is $10^9$ n/cm$^2$s. It will be possible to concentrate the neutron on a spot of about 1 mm$^2$, using a lens built to our specifications by X-Ray Optics in Albany/NY (USA). The target will be viewed by a pair- and a Compton-suppression spectrometer (CSS) working independently. Tomography type of work is planned.
THE POSSIBILITIES OF MONTE CARLO METHOD FOR NEUTRON AND GAMMA SPECTROSCOPY

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The main intent of this report is to attract the attention of physicists-experimentators to the modern and highly effective possibilities provided by the Monte Carlo method to the computer sampling and analysis of the interaction processes of particles with nuclei.

Various Monte Carlo method usage aspects are discussed such as planning, processing and informational output increasing of the n, γ experiments conducted for the evaluated data files verification and validation purposes.

Some questions of Monte Carlo method implementation for structural and parametrical identification of the nuclear processes are considered. Both direct and adjoined transport equation are used as a basic mathematical model for experiments description. This approach allows to estimate the variational functionals for the data under investigation with the help of the perturbation theory.

Code system BRAND current calculation features are discussed with regard to the transport equation and some other problems like direct n, γ transport, adjoined photon transport, direct usage of ENDF/B-VI data library, etc.

Experimental and Calculated Data for Estimating the Background from Natural Neutrons.  
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Determination of the dependence of the neutron fluence rate on elevation at small distances above the earth's surface is important, both for estimation of the neutron radiation contribution to the whole population dose and from the point of view of the influence of neutron radiation on detector background, as well. We carried out such the measurements at localities with various elevations from 113 m to 2632 m, placed between the geodetic latitudes 48° - 52° N and longitudes 16° - 20° E (Czech and Slovak Republic).  

The thermal part of the spectrum of natural neutrons $\Phi_\text{t}$ was detected directly by a proportional counter with a sensitive volume of $1 \times 10^4$ cm$^3$. In order to detect possible changes in the intermediate $\Phi_\text{i}$ and fast $\Phi_\text{f}$ components of ambient neutrons at different sites, we also used a $^3$He-counter, which was wrapped in layers of polyethylene (PE) moderators, 23 mm or 64 mm thick and covered by a thermal neutron absorber of Cd to shift the maximum of the response function into the intermediate or the fast neutron energy region. The spectrum of the ambient neutrons was determined using a calibrated Bonner spectrometer placed at the site with the highest elevation Lomnitsky Peak in the High Tatras, 2632 m. Measurements at the other sites were carried out only with the $^3$He-counter. We assumed that the shape of the neutron spectrum is elevation independent at low altitudes. Physical foundations for this assumption are the existence of an equilibrium distribution of low energy nucleons ($E < 500$ MeV) throughout the low altitude region in the atmosphere. The counting rates exhibited an exponential dependence on the elevation of the site $z$. Consequently, the neutron fluence rate and dose equivalent rate can be approximated by an exponential function in the form $\Phi(z) = \exp(\alpha z)$. From our experimental data, $\alpha = (0.85 \pm 0.05) \times 10^{-3}$ m$^{-1}$.  

Measurements were carried out at various localities with different relative concentrations of clay, sand and stone in the composition of ground. The results confirm that the elevation dependence of the neutron fluence rate and also dose equivalent can be approximated with the exponential functions with reasonable accuracy. The extrapolation of the height dependence counting rate to zero altitude gives the values: $\Phi(0) = (30 \pm 6)$ m$^{-2}$ s$^{-1}$, $\Phi_i(0) = (100 \pm 20)$ m$^{-2}$ s$^{-1}$ and $H(0) = (4.1 \pm 1.2)$ nSv/h.  

We compared our results with calculated values using the Los Alamos Code System (LCS) both for the sea level and maximum elevation sites. The LCS was also used for calculation of the latitude variations in the total neutron fluence rates. These values $k_\phi$ for sea level altitude are presented in Fig. 1. We normalized $\Phi(0)$ and $\Phi_i(0)$ (in accordance with the value $k_\phi = 1$ for the geomagnetic latitude $\phi = 90^\circ$) as latitude-independent parts, that is multiplied by the factor $k_\phi$. Then, the dependence of total and thermal neutron fluence rate on elevation $z$ and geomagnetic latitude $\phi$ can be expressed as  

$$ \Phi(z, \phi) = 119 k_\phi \exp(\alpha z) /1/ $$  

$$ \Phi_i(z, \phi) = 35 k_\phi \exp(\alpha z). /2/ $$  

Knowledge of the elevation and latitude dependence of the thermal component of the natural neutron fluence is important for determining the backgrounds of highly sensitive (with $\sigma$ = 1/v) neutron detectors, because it is determined mainly by this energy group. The effective area of neutron detector $C$ determined according to  

$$ N[s^{-1}] = C[m^2] \Phi [m^{-2} s^{-1}] /3/ $$  

which depends on the shape of the neutron spectra. For a homogeneous neutron field, it can be easily calculated or determined experimentally using /3/, where $\Phi$ is calculated from /2/ for a given locality. The influences of massive constructions, buildings, etc., and ground moisture content, are discussed in the paper.
There are only three experimental works about the simultaneous emission of two light charge particles (LCP) in the neutron induced fission of $^{235}$U and in the spontaneous fission of $^{252}$Cf and $^{248}$Cm [1-3]. The investigation of LCP correlations can provide new possibilities for studying the nuclear fission process.

A MULTiple-EMission (MULTEM) detector system to measure multiplicity, energy and angle correlation spectra of LCP emitted in both spontaneous and induced nuclear fission is described.

The MULTEM features providing the detection of rare fission events, where two or more LCP are emitted in coincidence with fission fragments, are as follows:

- detector main frame (evacuated stainless steel ball 29 cm in diameter) to hold fission fragment counters and the target holder, supplied with view windows for particle scintillation counters;
- an array of semiconductor detectors for fission fragments;
- 32-channel particle detector array based on CsI(Tl) scintillators coupled with view windows, light guides and photomultipliers;
- multiwire proportional chamber for precise determination of LCP angular distributions.

It is supposed to use silicon epitaxial detectors for registration of the fission fragments. These detectors have higher radiation resistance and less sensitivity to LCP, neutrons, $\beta$-particles and $\gamma$-rays accompanying the fission process. These peculiarities of the epitaxial detectors provide a possibility for long-time measurements without replacing the fission fragment trigger. Tests [4] of these detectors have shown that they satisfy the requirements for high quality spectrometry and time measurements. It is proposed to use CsI(Tl) scintillators coupled to FEU-87 photomultipliers for LCP detection. Preliminary tests using pulse shape analysis [5] have shown satisfactory identification of LCP with $Z \leq 4$ and their separation from $^{252}$Cf spontaneous fission $\gamma$-rays.

References

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Proton Polarized Filter of ITEP for Polarization of Neutrons

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Polarized neutron beams are the necessary tool for investigation of P- and T-odd effects in neutron nuclei interactions. Now the main direction of such investigations is concentrated in the resonance energy range of neutrons. Resonance polarized neutrons can be obtained by transmission of neutrons through the proton polarized target-filter (PPF). The cross-section of neutron-proton scattering in the singlet state is much larger than in the triplet state, so the neutron beam which will be transmitted through the PPF will be polarized in the wide energy range. A dynamically polarized proton filter was constructed in ITEP. PPF of ITEP includes the following components: 1) helium cryostat with \( ^4\text{He} \) evaporation refrigerator, operating at 1K; 2) superconducting magnetic system operating at 5T; 3) microwave power supply system operating at 140 Ghz; 4) nuclear magnetic resonance system operating at 200 Mhz; 5) data processing system.

The designed volume of target was about 100 cm\(^3\) (80 mm diameter, 20 mm thickness) so it is necessary to have a high cooling power refrigerator and powerful microwave generator for successful pumping of proton polarization. The liquid helium tests have demonstrated high cryogenic qualities of PPF. Liquid helium consumption was about 0.8 l/h at 320 A current in superconducting magnet. The cooling power of \( ^4\text{He} \) evaporation refrigerator was 2 W at 1.2K. We used propanediol with EHBA-CrV complexes as a target material, it was prepared in the form of beads about 1.5 mm diameter to increase the thermal contact with \( ^4\text{He} \). For dynamic polarization 140 Ghz microwaves were supplied to the cavity with target material. The polarization was determined by comparing enhanced NMR signals with thermal equilibrium signals. Proton polarization of up to (95±5)\% was achieved in our last experiment.
LOW ENERGY FISSION

STANDARD FISSION MODES OF THORIUM-233

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ABSTRACT

Mass and kinetic energy distributions have been investigated for the fragments of neutron induced fission of thorium-232 in the region of vibrational resonances. Structure of the fission barrier is responsible for the variation of both total kinetic energy and yields of standard-I and standard-II components of fragments mass spectra. Strong correlations of those variations and barrier penetration function structure (or fission cross-section) near the threshold were analyzed and explained within the framework of Brosa-model (see figure). The data presented suggested that so-called bifurcation point of mass-asymmetric fission valley must be found before outer saddle point. Detailed investigations of mass-angle correlations for thorium are definitely needed like it was made for uranium-237 around the vibrational resonance. Systematical study of thorium fission fragments is planning to perform using 2π detector - Frisch-gridded ionization chamber of IPPE installed on neutron channel of KG-2.5 accelerator.

Figure. Correlations of Standard-I fission mode of $^{233}$Th (in %) and fission cross section $\sigma_f$ and fragments total kinetic energy TKE (in arbitrary units).
STATUS OF FISSION EXPERIMENT WITH $^{235}\text{U}$ ALIGNED TARGET

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H.Postma (Delft University of Technology, Delft, The Netherlands.)

Series of measurements of fission fragment angular anisotropy of resonance neutron induced fission of $^{235}\text{U}$ aligned target has been completed using a refrigerator, designed in Obninsk. The work was performed at the IBR-30 + LEA-40 booster in Dubna.

First results on $A_2$ for resonances in the region below 40 eV are shown. The results are partly in agreement with those from the experiment of Postma and Pattenden, while for several resonances new values of $A_2$ are systematically lower. The energy dependence $A_2(E)$ has been investigated in the energy interval 0.3 - 15 eV, which has not confirmed the Moor’s calculations on the basis of the R-matrix multilevel multichannel approach without taking into account an interference between resonances with different spins. This fact is considered as an argument in favor of Furman-Barabanov theory, which includes the above mentioned interference.

The characteristics of the experimental setup after it’s modernization, including installation of a new refrigerator, fragment detectors and target samples, are reported.
THE MEASUREMENT OF THE GAMMA-RAY MULTIPlicity SPECTRA AND THE ALPHA VALUE FOR URANIUM-235 AND PLUTONIUM-239

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Abstract: Gamma-ray multiplicity spectra from 1 to 12 fold coincidence were measured on the 500m flight path of the IBR-30 by means of a 16-section NaJ(Tl) crystal scintillation detector with a volume of 36 l [1] for two 90%-uranium-235 and 10%-uranium-238 metallic samples with a thickness of 0.00137 atoms/barn and 0.00411 atoms/barn and for one 95%-plutonium-239 metallic sample with a thickness of 0.00195 atoms/barn.

Multiplicity spectra were obtained from experimental time-of-flight spectra after subtracting background components. Resonances with small and big fission widths were used for multiplicity spectra separation of other resonances into the two components of fission and radiative capture processes.

A distinction between the two parts of the summed multiplicity spectra permits one to determine the alpha value: \( \alpha = \frac{\sigma_r}{\sigma_f} = \frac{\Sigma K_{ir} \varepsilon_r}{\Sigma K_{if} \varepsilon_f} \), where \( \sigma_r \), \( \sigma_f \) - are the radiative capture and fission cross-sections; \( \varepsilon_r, \varepsilon_f \) - the efficiencies of registration of capture and fission gamma-quanta; \( K_{ir}, K_{if} \) - the i-th fold coincidence of radiative capture and fission events. Spectra of multiplicities and the alpha value were obtained for the resolved resonances of \(^{235}\text{U}\) and \(^{239}\text{Pu}\).

Similar data were calculated from BROND-2, ENDF/B-6, JENDL-3 evaluated data libraries with the help of the GRUCON computer program.

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Above-threshold structures in Cm neutron-induced fission reaction cross sections

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The broad quasi-resonance structures in N-even curium target nuclei fission cross sections are interpreted within a statistical model. The structures occur at incident neutron energies above the fission threshold, i.e. in the plateau region. They are well-pronounced in bomb-shot data by Fomushkin et al. (1980,1982) and Moore et al. (1971) for $^{244}$Cm(n,f), $^{246}$Cm(n,f) and $^{248}$Cm(n,f) reactions. These structures are interpreted in terms of double-humped fission barrier model within a convenient statistical theory approach. The total nuclear level density is represented as the factorized contribution of quasi-particle and collective states. We suggest that the intrinsic quasi-particle state densities in fissioning compound nuclei as well as residual nuclei play an essential role. The estimates of single- and three-quasi-particle intrinsic states densities for fissioning nuclei and two-quasiparticle intrinsic states densities for residual nuclei are obtained. The proposed approach is supported by the observation of similar effects in Pu nuclei level densities, manifested in $^{239}$Pu(n,2n) reaction cross section (Maslov V.M., 1994). The step-like structure, appearing in this reaction cross sections was interpreted in terms of jump-like excitation of two-quasi-particle states in residual nuclide $^{238}$Pu. The estimates of n-quasi-particle state densities obtained within a bose-gas model for different nuclides are fairly consistent.

Delayed Neutron Yields from Thermal Neutron Fission of
$^{235}$U, $^{233}$U, $^{239}$Pu and $^{237}$Np

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The measurement of delayed neutron (DN) yields from fission of $^{235}$U, $^{233}$U, $^{239}$Pu and $^{237}$Np by thermal and cold neutrons was carried out on the pulsed reactor IBR-2. The method of periodical irradiation and in-beam registration of delayed neutrons were used. The facility allows to measure DN yields with thermal neutron flux $6.10^{+5}$ n/cm$^2$.s and time interval between neutron bursts $t=200$ ms or 400 ms.

The DN decay curve for $^{235}$U was recorded for about 100 hours with a statistical accuracy of 0.3% per channel.

The obtained data give a possibility to check different parameter sets for yields and half-lives of DN groups available and to choose the most suitable of them.

The possibility of existence of DN group with $T_{1/2} < 100$ ms is estimated, too.
MULTIPLICITY OF LIGHT PARTICLES IN HEAVY ION INDUCED FISSION
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There exist a lot of clear evidences, that nuclear dissipation plays an important role in processes including large amplitude collective motion of nuclear matter [1, 2]. One of the most interesting example of such processes is nuclear fission [3]. In analyses of fission data, the information on conservative potentials, statistical characteristics of excited nuclei (for example, level density in extremal points of fission barrier), as well on dynamical peculiarities of this process is determinative.

In the present work, the experimental data on pre- and post- fission multiplicities of light particles emitted in fission of high excited nuclei was analysed in the framework of the statistical model of nuclear reactions taking into account fission dynamics. In this connection, we took into account the next dynamical effects:

1. dissipation effects the flow in the saddle point resulting in a smaller Bohr-Wheeler width;
2. the fission decay width is time dependent one;
3. dissipation leads to delay of the transition from saddle to scission.

The influence of different types of the energy dependence of nuclear dissipation on light particle multiplicity, fission cross section and other characteristics was studied. Sensitivity of these characteristics to level density parameters and maximal angular momenta was also analysed.

References

STUDY OF NEUTRON PROPERTIES IN QUARK POTENTIAL MODEL APPROACH

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The unambiguous evaluation of neutron electromagnetic characteristics - its mean square charge radius $< r_n^2 >$, electric polarizability $\alpha_n$ and magnetic polarizability $\beta_n$ is still an open problem from both the experimental and theoretical point of view. We study the electromagnetic features of nucleons in the framework of non-relativistic quark model (NRQM), using the solutions of three quark system Schrödinger equation obtained by hyperspherical harmonic (HH) method, taking into account the $SU_3 \times O_3$ multiplet structure and employing the $q-q$ interaction potential [1-3], characterized by confinement term $(-V_0 + A \cdot r_{ij}^2)$, one-gluon exchange and electromagnetic Coulomb term $((k_\alpha s + \alpha Q_i Q_j)/r_{ij})$ and the contact spin-spin interaction term $((k_\alpha s + \alpha Q_i Q_j) \cdot C \pi b(r_{ij}) f_i^g/2)$, treated as perturbation.

The analytical expressions for neutron's MSCR $< r_n^2 >$ and electromagnetic polarizabilities $\alpha_n, \beta_n$ have been derived. These expressions contain the contributions also from the matrix elements of mixed-symmetry components ($\psi_{m^s}$) on the total neutron ground state wave functions.

The neutron electromagnetic polarizabilities and MSCR values have been calculated using various sets of NRQM parameters $(V_0, A, \alpha_s, C)$. The comparison of the obtained neutron polarizability $\alpha_n$ and MSCR $< r_n^2 >$ values with latest experimental data [4] was made. The controversial situation connected with $< r_n^2 >$ interpretation and its relationship with the neutron-electron scattering length $b_{ne}$ was analyzed as well.

References

Parameters found in effects of presence of very stable excitations in some near-magic nuclei and proximate to them stable intervals (parameters of nonstatistical effects) in middle part of excitation spectra of near-by nuclei were compared with values of stable intervals at higher excitations which are seen as nonstatistical effects in spacing distribution of neutron resonances. Integer relations in the values of stable intervals in high-energy nuclear excitations are compared with properties of low-lying two-phonon excitations and also with long-range correlations in nuclear excitations and in binding energies of near-magic nuclei. Possible general or even fundamental meaning of observed effects is discussed in separate papers [1,2] where example of integer relations in ground state band of nucleus $^{116}$Te with two valence protons above Sn-core with $Z=50$ and $N=64$ is shown. Harmonic character of the first three excitations with value 681 keV, near equidistancy in next four excitations with mean value $\langle 9/8 \rangle$ 681 keV =766 keV and excitation between $16^+$ and $18^+$ levels with value $\langle 6/8 \rangle$ 681 keV =511 keV =Δ are resulted in proximity of three excitations of this nucleus to the integer values of the single parameter $\Delta$ (that’s 7, 10 and 11 values of $\Delta=511.0$ keV). Presence of analogous stabilization effects in excitations and in binding energies of great number of nuclei around different nuclear shells is connected with the discreteness in the parameters of residual nucleon interaction with the period $(1/8) 681$ keV = $(1/6) \Delta =85$ keV. Small intervals superimposed on such fine-structure effects are observed and found to be quantitatively estimated as super-fine structure with periods multiple to $D=594(2)$ eV seen directly in spacing distributions in nuclei with $Z=51,52,53$ (close to $Z=50$). Proximity of parameter $\Delta$ to the electron rest mass value and of ratio 594 eV/511 keV to the value of radiative correction of electrodynamics was discussed in [2].

Three regions of $Z,N$ where such effects are observed in low-lying levels and expected to manifest itself in high-energy excitations but where very few data on neutron resonances exists were found. We propose to investigate resonance spacing distribution by time-of-flight method in the neutron energy region up to 2-3 keV by LNPI spectrometer GNEISS and from 2-3 keV up to unresolved region by one of spectrometers with LINAC. Analysis of existing data for these three regions ($Z=31,32,34$; $Z=50-51$ and $Z=78-80$) will be given. Set of PC-oriented programs for evaluation of stable intervals in complex nuclear spectra will be discussed. With the help of some transparent methods of correlation analysis of exact rational relations in energy intervals and estimation of parameters of nucleon interactions several common regularities in nuclear data can be observed.

REFERENCES

Nonstatistical effects in resonance parameters of heavy and fissile nuclei

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In sixties superfine-structure in $^{232}$Th nearest-neighbors neutron level spacing distribution was found in the work of Columbia University Nevis Cyclotron Group [1]. To study such effects in data for all transactinium elements their resonance parameters were collected and nonstatistical effects in positions ($E_n$) and in spacing ($D=E_n^1 - E_n^2$) distributions were investigated. Preliminary analysis of sum spacing distribution of the relatively strong ($\Gamma_n^* \geq 1$ meV) neutron levels of five even-even target-nuclei $^{232}$Th, $^{234}$U, $^{238}$U, $^{240}$Pu and $^{242}$Pu has shown [2] nonstatistical effect in the form of several maxima situated at integer number ($n=1,4,5,10,12$) of the stable interval in one of them ($D=143$ keV in all levels of $^{234}$U).

Inclusion of resonance parameters of four fissile isotopes from R-matrix analysis (see Table) permitted to enlarge number of nuclei investigated. Values of stable intervals of the order of 1 keV were compared with the positions and spacing of levels with extremely large fission widths. For example position ($E_n=285.3$ eV) of the single known neutron level in $^{239}$Pu with large $\Gamma_f$ turned out to be coinciding with the twofold value of period in system of intervals $D=n\times143$ eV found in combined distribution of relatively strong neutron levels of neighboring nuclei and in some middle-weight isotopes [2].

Table. Number of resonances known from different Reich-Moore R-matrix Analysis.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Isotope</th>
<th>Energy range, eV</th>
<th>Number of resonances</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.Derien</td>
<td>$^{233}$U</td>
<td>0-150 eV</td>
<td>-</td>
<td>N.S.T.,31,379(1994)</td>
</tr>
<tr>
<td>G. de Saussure et al.</td>
<td>$^{235}$U</td>
<td>-</td>
<td>-</td>
<td>N.S.E.,103,109(1989)</td>
</tr>
<tr>
<td>L.C. Leal et al.</td>
<td>$^{235}$U</td>
<td>0-500 eV</td>
<td>912</td>
<td>N.S.E.,109,1(1991)</td>
</tr>
<tr>
<td>R.B. Perez et al.</td>
<td>$^{239}$Pu</td>
<td>0-40 eV</td>
<td>19</td>
<td>N.S.E.,93,31(1986)</td>
</tr>
<tr>
<td>H.Derien, G. de Saussure</td>
<td>$^{239}$Pu</td>
<td>0-1000 eV</td>
<td>387</td>
<td>N.S.E.,106,434(1990)</td>
</tr>
<tr>
<td>H.Derien</td>
<td>$^{239}$Pu</td>
<td>1000-2500 eV</td>
<td>-</td>
<td>ORNL/TM-10986</td>
</tr>
<tr>
<td>H.Derien et al.</td>
<td>$^{241}$Pu</td>
<td>0-100 eV</td>
<td>171</td>
<td>N.S.E.,96,58(1987)</td>
</tr>
<tr>
<td>H.Derien, G. de Saussure</td>
<td>$^{241}$Pu</td>
<td>0-300 eV</td>
<td>239</td>
<td>ORNL/TM-11123</td>
</tr>
</tbody>
</table>

REFERENCES

New approaches to test T-invariance of fundamental interactions are of great interest. In Refs.
[1-3] the possibilities of modern experiment on muon capture have been considered with respect to T-invariance study. In particular the reactions with transitions to continuum \( \mu \rightarrow n + n + \nu_e \) and \( \mu + ^3He \rightarrow d + n + \nu_e \) were discussed in Ref.[2]. It was shown that neutron polarization along \([n_k \times n_\mu]\), where \(n_k\) and \(n_\mu\) are unit vectors along neutron momentum and muon polarization axis, respectively, should be sensitive to T-invariance violation both in weak lepton-nucleon hamiltonian and in nucleon-nucleon interaction.

Few nucleon systems are of prime importance for study of T-noninvariant components of nucleon-nucleon potentials. Only for them the experimental results may be related reliably with constants of hamiltonian. In the last few years much success was achieved in microscopic description of \(A=6\) nuclei as three body systems \(\alpha + N + N\) in the framework of the method of hyperspherical functions (see, e.g., Refs.[4-6]).

We consider T-noninvariant transverse polarization for neutrons from reaction of muon capture by \(^6Li\) nucleus with decay to resonance \(2^+\) continuum state of three particles \(\alpha + n + n\). This polarization is normal to the plane formed by polarization axis of initial mesoatom and neutron momentum. A situation is analyzed when neutrons have equal and opposite directed momenta which are perpendicular to the axis of meson polarization. Wave function of final state is constructed in the framework of the method of hyperspherical harmonics. For the allowed Gamov-Teller transition \(1^+ \rightarrow 2^+\) neutron polarization is expressed by T-noninvariant relative phase of reduced matrix elements of transitions from the ground state of \(^6Li\) nucleus to different configurations of final state.

The high efficiency and low background spectrometer for investigation of gamma-cascades on neutron resonances has been built to find neutron resonances of the $^{178m^2}$Hf isomer of exotic structure. The first measurements have been carried out by the spectrometer using 20 ng (1%) $^{178m^2}$Hf target. For the first time, one of resonances of the isomer has been observed. The features of this resonance have been considered.
EXTRAORDINARY EXCITED STATES OF Gd-158

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The fluctuation of various gamma-cascades emission probability for neutron resonances of Gd-157 has been measured to find and investigate extraordinary states of excited nuclei. The fluctuation of a gamma-quanta spectrum in the range of unresolved transitions has been revealed. The peculiarities in level density have been found and information on the presence of extraordinary excited states in the range below the neutron binding energy has been obtained.
The measurements of a gamma-cascade spectrum for neutron resonances of the ore rock samples containing precious metals have been performed. It has been shown that the techniques to be used allow a definition of very small concentration of precious metals. In particular gold in the siliceous samples was found at the concentration of 0.2 g/t.
Shell stabilization of excitations in odd-odd nuclei

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The discretion in the values of parameters of residual nucleon interaction on different shells calculated from the differences of nucleon separation energies (from linear dependence of the values of valence nucleon separation energies) were found in agreement with values of stable excitations of some near-magic odd-odd nuclei. From exactly known energy levels of nuclei $^{132}\text{Sb}, ^{131}\text{Sb}, ^{130}\text{Sb}$ originated from residual interaction of valence proton and one, two and three holes in major $N=82$ shell we may estimate following intervals and ratios between them:

$^{132}\text{Sb}$ (g.s. $J^* = 4^+$) - 85.55(6) keV, $J^* = 3^+$ - 426.07(6) keV, $J^* = 2.3^+$, interval 340.52 keV, ratio of their values = 3.98;

$^{131}\text{Sb}$ (g.s. $J^* = 7/2^+$) all known levels form quintet of states from interaction of single-particle state with two hole excitation in $^{130}\text{Sn}$. Energies of 3/2$^+$, 7/2$^+$, 11/2$^+$ states are separated by intervals $D=339.51(15)$ keV and $D=84.40$ keV, ratio of their values = 4.02;

$^{130}\text{Sb}$ (g.s. $J^* = 8^-$ and 5$^+$) - 84.70(9), $J^* = 6.7. 8^-$ : the third excitation with positive parity $J^* = 3.4, 5^+$ $E^* = 341.29$ keV, ratio of their values = 4.03.

In Table values of separation energies of valence proton $Z=51$ are given in comparison with rational parts of the parameter $\epsilon_o = 1022$ keV = $3 \times 340$ keV derived from the value of $S_p = 5\epsilon_o$ (see numbers in boxes for this value and for exactly integer to it value $S_{p2n}$ - separation of tritium combination of nucleons). Small differences between real and estimated values are shown.

Energy levels of odd-odd nuclei $^{122,124}\text{Sb}$ and $^{128,130}\text{I}$ were studied in PNPI and are well known. Some rational relations between their energies are conserved and for example in $^{128}\text{I}$ ($J^* = 1^+$, g.s.) energy values for the 2-nd ($J^* = 3^+$, 85.470(3) keV) and 3-rd levels ($J^* = 4^+$, 128.236(1) keV) are in 3/2 relation (ratio 1.50036).

Proximity of values of splittings inside members of the multiplets was observed in $^{124}\text{Sb}$ by Sakharov. In adopted levels file ENSDF following splittings are seen in $^{124}\text{Sb}$: 6.4612(15) keV and 6.516(4) keV ($J^* = 5^-, 6^-$), 6.412(7) keV ($J^* = 7^-$) and 6.576(16) keV. Small splitting 0.606(5) keV is close to observed in neutron resonances stable interval $D=0.594$ keV. Intervals close to 6.5 keV are seen in levels of $^{128}\text{I}$ - 6.6506(20) keV ($J^* = (4)^-$ and (?)$^-$) and in levels of $^{130}\text{I}$ - 6.555(5) keV ($J^* = 2^+$ and (1,2,3)$^+$) with ratio 11.04 to the same interval $D=0.594$ keV in high energy levels of this nuclei.
<table>
<thead>
<tr>
<th>$^A Z$</th>
<th>$^{109}Sb$</th>
<th>$^{111}Sb$</th>
<th>$^{113}Sb$</th>
<th>$^{115}Sb$</th>
<th>$^{116}Sb$</th>
<th>$^{117}Sb$</th>
<th>$^{119}Sb$</th>
<th>$^{121}Sb$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_p, \text{keV}$</td>
<td>1531</td>
<td>unknown</td>
<td>3055</td>
<td>3733</td>
<td>4074</td>
<td>4406</td>
<td>5109</td>
<td>5777</td>
</tr>
<tr>
<td>$n \times \varepsilon_o$</td>
<td>1533</td>
<td>-</td>
<td>3066</td>
<td>3748</td>
<td>4088</td>
<td>4428</td>
<td>5110</td>
<td>5792</td>
</tr>
<tr>
<td>$n$</td>
<td>3/2</td>
<td>-</td>
<td>3</td>
<td>11/3</td>
<td>4</td>
<td>13/3</td>
<td>5</td>
<td>17/3</td>
</tr>
<tr>
<td>Diff.</td>
<td>2(33)</td>
<td>-</td>
<td>11*</td>
<td>15*</td>
<td>14(5)*</td>
<td>22*</td>
<td>1(8)*</td>
<td>15*</td>
</tr>
<tr>
<td>$X$</td>
<td>58</td>
<td>60</td>
<td>62</td>
<td>64</td>
<td>65</td>
<td>66</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>$^A Z$</td>
<td>$^{108}Sn$</td>
<td>$^{110}Sn$</td>
<td>$^{112}Sn$</td>
<td>$^{114}Sn$</td>
<td>-</td>
<td>$^{116}Sn$</td>
<td>$^{118}Sn$</td>
<td>$^{120}Sn$</td>
</tr>
<tr>
<td>$\Delta E_B, \text{keV}$</td>
<td>25964</td>
<td>25703</td>
<td>25604</td>
<td>25601</td>
<td>-</td>
<td>25590</td>
<td>25547</td>
<td>25591</td>
</tr>
<tr>
<td>$25 \times \varepsilon_o$</td>
<td>25550</td>
<td>25550</td>
<td>25550</td>
<td>25550</td>
<td>-</td>
<td>25550</td>
<td>25550</td>
<td>25550</td>
</tr>
<tr>
<td>Diff.</td>
<td>414(56)</td>
<td>153(32)</td>
<td>54(16)</td>
<td>51(5)</td>
<td>-</td>
<td>40(2)</td>
<td>-3(4)</td>
<td>41(5)</td>
</tr>
</tbody>
</table>

Set of PC-oriented programs for evaluation of stable intervals in complex nuclear spectra will be discussed. With the help of some transparent methods of correlation analysis of exact rational relations in energy intervals and estimation of parameters of nucleon interactions several common regularities in nuclear data can be observed.
In the Born approximation Foldy's equation for the neutron mean square intrinsic charge radius $<r_n^2> = 3\hbar^2/(Me^2)(a_{ne} - a_F)$, where $a_{ne}$ is the neutron-electron scattering length and $a_F = \mu_n e^2/(2Mc^2) = -1.468 \times 10^{-3}$ fm, can be obtained not only on the basis of the generalized Dirac equation, but from the formula for the charge formfactor $G_E(q^2) = F_1(q^2) + q^2 \hbar^2/(4i\lambda^2 c^2)\mu_n F_2(q^2)$, as well, where $F_1(q^2)$ and $F_2(q^2)$ are the Dirac and Pauli formfactors.

If Foldy's formula is correct, then the positive sign of $<r_n^2> = -1.31 \times 10^{-3}$ fm, cannot be explained in the framework of modern theoretical ideas of the nucleon (e.g., Cloudy Bag, Collective, Skyrme, Nambu-Jona-Lasinio models, etc).
The neutron-electron scattering length \( (a_{ne}) \) from the data of neutron transmission and interferometry experiments with the one and the same sample is discussed. It is shown, that it allows to obtain \( a_{ne} \) without the use of additional information about the resonance structure and potential scattering lengths of isotopes.
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