Excited State β-Decays the r-Process

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β-Decays of excited-state nuclei are calculated using a single-particle model, which incorporates shell energies of individual nucleons into the mass formula. Energies of two-particle levels are calculated by assuming a Fermi gas model with shell and pairing forces. A comparison of level energies to those of the spherical shell model for nuclei of the same mass yields a determination of a configuration mixture of spherical shell model eigenstates characterized by their quantum numbers. Therefore, the order of the decay is specified. The resulting density of particle states is inserted into the gross theory of β-decay, so the ease of calculation is maintained with the decay form factors. This model is quite useful in that β-decays of individual nucleons can be deduced. In addition, decays of excited state nuclei, which are created by the promotion of nucleons to levels above the Fermi surface, can be calculated with the same method. The ultimate purpose of this calculation is to determine the effects of excited-states – specifically, β-decays – on the r-process of nucleosynthesis. Since r-process progenitor nuclei are very neutron rich, decay rates must be calculated, and current models have utilized only ground-state nuclear decay rates. The possibility of a faster progression along the r-process path, as well as the possible elimination of closed-shells in a small population of the N=82 nuclei due to excitations above the shell may create an r-process simulation in which the mass 195 nuclei are produced in greater abundance by the time the r-process freezes out. An r-process model which evolves average β-decay rates as a function of temperature is used. The environmental parameters of this model simulate those of the supernova hot-bubble region, a strong candidate for the r-process site. The final freezeout abundance distribution is compared with that of the solar system r-process abundance distribution.

Tuning Effect in Nuclear Binding Energies

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Data files of experimental nuclear binding energies (E_B), mainly from AME-95 [1], and nucleon separation energies (S_N, S_{2N} etc.) together with E_B from different theoretical models (FRDM, FRLDM, RMF, ETFSI-1, HFBCS-1, KUTY) were used to study the observed in [2] stable character of intervals in binding energies (tuning effect in E_B). This effect was checked in [3-5] by observation of maxima in several distributions of ΔE_B in a broad scope of nuclei with certain combinations of differences of Z and N. Tuning effect exists only in experimental data and in Fig.1-2 some additional correlations with a period Δ=4.6 MeV found in [2] are shown.

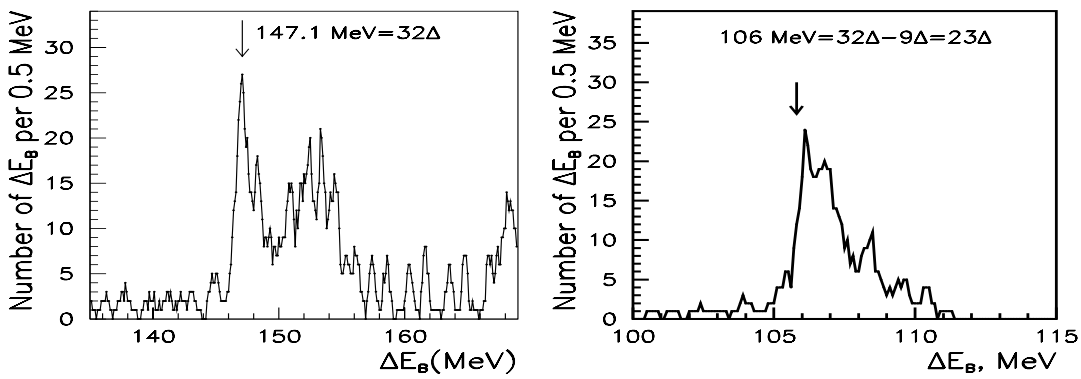

Fig.1. Differences of E_B in nuclei with ΔZ=8, ΔN=14 (left) and ΔZ=6, ΔN=10 .

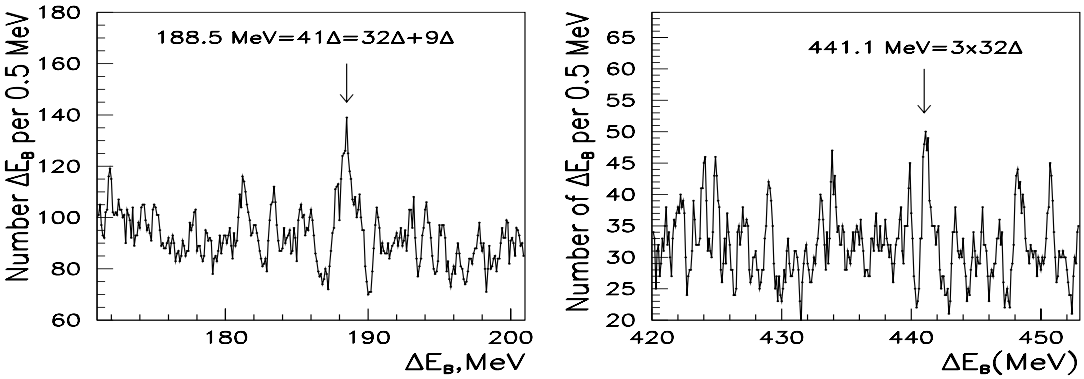

Fig.2. Differences of E_B in N-even nuclei (left) and in odd-odd nuclei [4].

The role of RIB-data in the check of the tuning effect in E_B as a phenomenon of the hadronic physics and possible connection of these effects with some unsolved problems of the Standard Model [6] will be discussed.

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DIRECT OBSERVATION AND INVESTIGATION OF CONTROLLING AND BREAKING SPONTANEOUS GAMMA-DECAY OF RADIOACTIVE NUCLEI BY THE METHOD OF DELAYED GAMMA-COINCIDENCE

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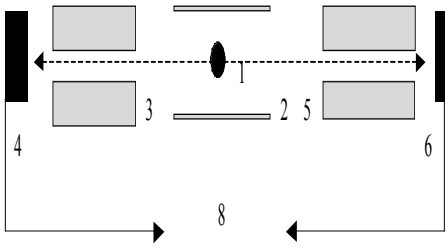
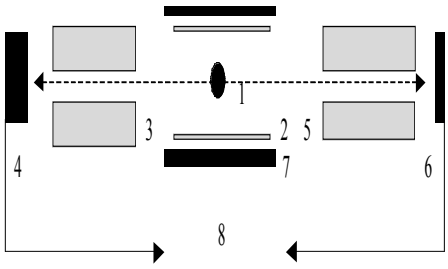
The paper discusses the theoretical model and results of direct experimental investigation of the phenomenon of controlling the probability of spontaneous gamma-decay and life-time of radioactive $Co^{57}(Fe^{57*})$ nucleus. The phenomenon of controlled nuclear decay is a result of interaction of the each excited nucleus with zero-energy electromagnetic modes, which in turn interact with the controlling and controlled thin resonant screen [1]. In our previous investigations the phenomenon of controlled decay was studied by the indirect methods both intensity [2] and spectral width [3] measurements of the emitted gamma-radiation.



The aim of the present experiment was to investigate the law of controlled gamma-decay of radioactive $Co^{57}(Fe^{57*})$ nucleus by the direct method of delayed gamma-gamma coincidence. A $Co^{57}(Fe^{57*})$ radioactive isotope with energy $h\omega_{21}$=14,4 KeV and very small activity Q=0,1 mKu was used as a source of controlled (suppressed) Mossbauer gamma-radiation 1. In the first case the source was put in the center or near the edges of the thin resonant screen 2, had a form of cylinder made of stable Fe^{57} isotope. In the second case another thick cylinder 7 made of lead was put around the resonant absorber cylinder. It totally absorbs both resonant and non-resonant radiation in the range of energies close to $h\omega_{21}$=14,4 KeV. Behind the diaphragm 3 there was an amplitude detector 4 (thick NaJ(Tl) crystal) for detecting of first quantum of decay gamma cascade with energy E_{32} = 122 KeV. Behind the diaphragm 5 there was another amplitude detector 6 (thin NaJ(Tl) crystal) for detecting the second quantum of decay cascade with energy E_{21} =14,4 KeV. The law of gamma-decay of the second transition of the cascade in the final ground state of Fe^{57} nucleus was the object of our investigation. Two signals from the detectors 4 and 6 were used for measuring of time-dependent law of gamma-decay in the processing system 8.



In the experiments we have discovered the change (increase) of radiative life-time of radioactive nucleus Fe^{57*} by 10-40 % (in relation to resonant Mossbauer gamma-channel of decay) and total life-time (including non-controlled non-Mossbauer gamma-radiation and non-controlled electron conversion channels of decay of an excited nucleus) by 1 %. For the first time the magnitude $\Delta\omega_0 \approx 10^{11}$ s^{-1} and positive sign of the radiative shift of first excited nuclear level of Fe^{57} nucleus (nuclear analogy of the electron Lamb shift) were founded in these experiments. The outcomes of the experiment correspond to the predictions of the controlled gamma-decay theory [1].

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Decay studies of proton-radioactive nuclei at the HRIBF *

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The investigations of proton radioactivity at the Holifield Radioactive Ion Beam Facility will be presented. The highlights include the identification of five new proton emitters, ^{140}Ho, ^{141}mHo [1], ^{145}Tm [2], ^{150m}Lu [3] and ^{151m}Lu [4], as well as the recent observation of fine structure in proton emission from ^{146}Tm [5] and ^{145}Tm [6]. The latter emitter was studied using a novel technique based on the digital processing of the detector signals at the Recoil Mass Separator.

The observed properties of proton emission are interpreted within a spherical approach [7,8] as well as within advanced models accounting for deformation [9,10]. These results contribute to the understanding of the structure of nuclei beyond the proton-drip line including the evolution of proton single-particle levels, nuclear shapes and energy surfaces. Recently, the $s_{1/2}$ and $h_{11/2}$ neutron levels in exotic N=77 isotone ^{145}Er were identified in the study of proton-radioactive odd-odd ^{146}Tm [5]. The transitional properties ($\beta_2 \approx 0.18$) of ^{144}Er were deduced from the 0.33 MeV excitation energy of the 2^+ level populated ($I_p \approx 9\%$) in the proton emission from the 3 μs activity of ^{145}Tm [6].

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Observation of the Gamow-Teller Resonance in Beta Decay of Neutron-deficient Nuclei near ^{100}Sn

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Neutron-deficient isotopes near the doubly magic ^{100}Sn nucleus were studied intensively during the last years, especially in terms of the problem of missing strength in Gamow-Teller(GT) β decay [1]. At GSI, we produce those nuclei by using the mass separator on-line to the heavy-ion accelerator UNILAC. As part of an ongoing research program on β decay near ^{100}Sn, we investigated ^{97}Ag and ^{98}Ag by using, as complementary spectroscopic tools, a Total-absorption Spectrometer (TAS) [2] and an array of 6 Euroball-Cluster Ge detectors (Cluster Cube) [3]. The TAS is a highly efficient NaI detector, which allows measuring the β-intensity distribution rather than the individual γ rays. The Cluster Cube represents a compromise between high resolution and high efficiency. The evaluation of TAS data depends strongly on the knowledge of the response function of the TAS for each particular cascade. The information required to obtain the response function concerns excited levels and their de-excitation patterns, which can be determined only from high-resolution experiments. Thus, the "double strategy" of combining high- and low-resolution studies provides a tool to map the GT-strength distribution to high-excitation energies in the daughter nucleus.

Based on the analysis of the Cluster Cube data [4,5], 603 γ lines (578 new) were placed in a decay scheme of ^{97}Ag, which includes 151 excited states (132 new) of ^{97}Pd, while 438 γ lines (414 new) and 173 excited states (163 new) were identified in the case of ^{98}Ag. The "peel off" method [6] was used for evaluating the TAS data. For ^{97}Ag, good agreement was achieved between TAS and Cluster Cube data, the summed GT-strengths being 3.00(40) and 2.02(40), respectively. These results are considerably higher than the value of 0.44 obtained in a previous experiment [7] using standard size Ge detectors. For ^{98}Ag, the GT strength is 2.7(4) from the TAS. However, the Cluster Cube data for ^{98}Ag still miss a considerable amount of β intensities in the high-energy region, and thus it is not appropriate to derive a GT-strength distribution directly from it.

The extreme single-particle model expects the decay of ^{97}Ag and ^{98}Ag to be dominated by the "core decay", i.e. to mainly populate, after breaking a *g9/2* pair, the 3*qp* and 4*qp* states, leading to a resonance at ^{97}Pd and ^{98}Pd excitation energies of ~4 MeV and ~5.5 MeV, respectively. This GT resonance is clearly revealed by the experiment except for the Cluster Cube data in the case of ^{98}Ag. The shell-model calculations within a so-called restricted SNB basis [8] reproduce both the centroid and the width of the GT resonance in both cases, despite a discrepancy in the summed GT-strengths. The GT-hindrance factors with respect to the TAS results amount to 4.3(6) and 4.6(6) for ^{97}Ag and ^{98}Ag, respectively, in agreement with the values expected from further configuration mixing within SNB model space. These large hindrance factors are a direct indication for the complexity of the actual nuclear wave functions compared to what one expects from the simplest single-particle shell model.

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High accuracy mass measurements of short-lived nuclides for fundamental studies with the ISOLTRAP spectrometer.

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The atomic mass is a gross property of the nuclide that embodies all the effects of the forces that are interplaying within its nucleus. Hence, high accuracy mass measurements are prerequisites for many of the past and present studies that use the nuclei as a laboratory to investigate fundamental interaction.

Examples are the tests of the Conserved Vector Current (CVC) hypothesis as well as the unitarity of the CKM matrix, which require a high accuracy investigation of superallowed β-decays. Until now 9 superallowed beta decays have been measured to very high precision. Additional interesting candidates in this context are ^{34}Ar, due to its large predicted Coulomb corrections, and ^{74}Rb, which provides a CVC test at high Z. Among others a very accurate Q-value of the β-decay of the investigated nuclides is needed, requiring precise mass values of mother and daughter nuclei.

Another example is the isobaric multiplet mass equation (IMME), that supplies a quadratic correlation between the mass and the isospin projection of members of an isospin multiplet. To test this equation, the mass of at least four members of an isospin multiplet has to be known with high accuracy. Some of these masses are ground state masses and thus accessible by direct mass spectrometry as done with the ISOLTRAP mass spectrometer.

ISOLTRAP is a Penning trap mass spectrometer installed at the online isotope separator ISOLDE/CERN. The mass separated 60-keV ion beam from ISOLDE is guided to the ISOLTRAP set-up. It consists of three main parts: (1), a linear gas-filled radiofrequency quadrupole (RFQ) trap for retardation, accumulation, cooling and bunched ejection at low energy, (2), a gas-filled cylindrical Penning trap for isobaric separation, and (3), an ultra-high vacuum hyperboloidal Penning trap for isomeric separation and the mass measurement. The mass measurement is based on the direct determination of the cyclotron frequency $\omega_c = q/m \cdot B$ of a particle of mass m and charge q revolving in a magnetic field of the strength B.

We report on mass measurements of ^{33,34}Ar, $^{73..78}$Kr, and ^{74}Rb performed with the ISOLTRAP spectrometer. ^{74}Rb and ^{33}Ar are the shortest lived nuclides ever investigated in a Penning trap ($T_{1/2} = 65$ and 174 ms). The accuracy of their mass values is governed by statistics and resolving power, that are limited by production rate and half-life respectively. The relative accuracy reached is $1.2 \cdot 10^{-7}$ for ^{33}Ar and $\leq 4 \cdot 10^{-7}$ (i.e. ≤ 30 keV) for ^{74}Rb. For the longer lived nuclides ^{34}Ar and $^{74..78}$Kr a relative accuracy of less than $3 \cdot 10^{-8}$ was achieved. This level of accuracy has never been reached before in mass measurements of short-lived nuclides. With this result the Q-value for the β-decay of ^{34}Ar could be determined with an uncertainty below 1 keV.

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Decay Properties of N$\simeq$Z Nuclei: Progress Report from the GSI ISOL-Facility

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Proton-rich nuclei, situated at or near the N=Z line between the double shell closures ^{56}Ni and ^{100}Sn, have been produced by fusion-evaporation reactions, separated by using the Isotope Separator On-line (ISOL) of GSI Darmstadt, and investigated by means of decay spectroscopy. Particular recent highlights concern the β and γ decay of the 12^+ yrast isomer in ^{52}Fe [1], and the β-delayed γ rays or protons studied for ^{56}Cu [2, 3], ^{57}Zn [4], ^{60}Ga [5], ^{61}Ga [6], the odd-odd N=Z nuclei ^{62}Ga, ^{70}Br [7], ^{94}Ag [8], and the *rp*-process waiting-point nucleus ^{93}Pd [9]. By combining high-resolution and total-absorption γ-ray measurements, a resonance-like distribution of the Gamow-Teller strength was found for the β decays ^{96}Ag [10], ^{97}Ag [11], ^{98}Ag [12] and $^{100-107}$In [13]. Moreover, a triple α chain was observed, which starts at ^{114}Ba and ends at ^{102}Sn [14].

These experiments have yielded either the first observation of the respective decay or considerable improvements over previous work with respect to source intensity and/or purity, detection efficiency, energy resolution and/or counting statistics. Examples for the important role of the development of ISOL ion sources and detector techniques will be given. The nuclear structure aspects of the new experimental data will be discussed, including in particular the first measurement of B(E4) values in ^{52}Fe, the new information on hitherto-unobserved β-decay branches to excited states in the core nucleus ^{56}Ni (4^+,5^+) and in the single-proton nucleus ^{57}Cu ($5/2^-$,$7/2^-$,$9/2^-$), the experimental evidence for the occurrence of long-lived (high-spin) isomers in the N=Z odd-odd nuclei ^{62}Ga, ^{70}Br and ^{94}Ag, which are of interest, e .g., for future high-precision measurements of superallowed $0^+\rightarrow0^+$ transitions, the shell-model interpretation of the Gamow-Teller resonance near ^{100}Sn, and the new α-decay data beyond ^{100}Sn. This discussion will take points of astrophysical relevance into account.

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Search for Physics beyond the Standard Model via a Polarization-Asymmetry correlation experiment on ^{118}Sb

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Although the Standard Model (SM) of the electroweak interaction agrees with all experimental data [1], it has too many free parameters and ad hoc assumptions to be accepted as an "ultimate" description of nature. Parity violation in particular is "explained" by the assumption that only left-handed fermions and leptons participate in the charged current weak interaction. In the description of the weak interaction, parity violation is built in by introducing the helicity projection operator $(1-\gamma_5)$ in the Hamiltonian. Left-right symmetric (LRS) extensions of the SM, based on the $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group have been proposed to restore parity symmetry at high energies. Parity violation as observed at lower energies is then caused by a Higgs-type mechanism. The simplest extension of the SM is offered by the so called Manifest left-right symmetric model [2] which introduces a second charged gauge boson W_2. It acquires, by spontaneous symmetry breaking, a mass m_2 that is higher than the mass m_1 of the observed gauge boson. The two bosons are proposed to couple with the same coupling constant g to the left- and right-handed fermions with a mixing angle ζ.

$$W_L = W_1 \cos\zeta + W_2 \sin\zeta \qquad W_R = -W_1 \sin\zeta + W_2 \cos\zeta \tag{1}$$

From the propagators of the interaction $(q^2 + m_{1,2}^2)^{-1}$ it is easily seen that for $q^2 >> m_2$, i.e. at high energies, parity violation is restored. More general extensions [3] allow for different coupling constants and different Cabbibo-Kobayashi-Maskawa mixing matrices in the left- and right-handed sectors. In these general LRS models, experiments in β decay are complementary to μ decay measurements or to to direct searches for heavy W bosons because other combinations of parameters are probed.

We report on a recent experiment searching for right-handed currents in the ^{118}Sb nuclear β-decay that may be found in a small deviation from the full (100%) parity violation. For this purpose we have determined the correlation between the longitudinal spin polarization P and the β-emission asymmetry of the positrons from the ^{118}Sb decay. In general, the parameter P reflects the helicity structure of the weak interaction involved. When the decaying nucleus is polarized, it is possible to select the positrons that are emitted in the parity-forbidden direction. In this way the the contribution of "normal" particles associated with W_L is decreased while the amount of positrons coming from W_R is enhanced. As a result, the sensitivity of our method to right-handed currents is significantly improved. Moreover, by comparing positron spin polarization data from a polarized and unpolarized nuclear source, the measurement becomes independent of the precise knowledge of the analyzing power of the polarimeter. In this experiment the ^{118}Sb ($t_{1/2} = 3.5$m) activity was obtained as a daughter of ^{118}Te ($t_{1/2} = 6.0$d) produced at the ISOLDE isotope separator at CERN. The nuclei were polarized by means of low temperature nuclear orientation in the NICOLE on-line refrigerator at temperatures of about 8 mK. The emitted positrons were transported by an energy selective magnetic spectrometer to the polarimeter where the spin polarization of the positrons was measured by time resolved positronium spectrocopy. At the time of writing the analyses of the data is not fully completed. However, a preliminary assessment of the data indicates that a lower mass limit for the W_R of 350 GeV is within reach. This result makes the current experiment the best precision test of parity violation in nuclear β decay.

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Meson Exchange Current Effects studied in First Forbidden Nuclear Beta Decay in the Lead Region

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In an atomic nucleus, mesons are exchanged by the constituent nucleons . The influence of these Meson Exchange Currents (MEC) is revealed in nuclear beta decay by a strong enhancement of the time-like component of the weak axial vector current ($\int\gamma_5$) relative to its value deduced in the impulse-approximation [1]. The enhancement factor $\epsilon_{\rm MEC}$ can be determined by comparing measured ft-values of first forbidden β transitions with shell model calculations since the matrix element $\int\gamma_5$ contributes to these decays. For nuclei with $\mathrm{A} = 16 - 132$ is was found that the deduced values agree with MEC calculations that are dominated by soft-pion exchange. In the lead region ($A \approx 205$–212) however, the "experimental" $\epsilon_{\rm MEC}$ is significantly larger than the value expected from soft-pion exchange models [2]. In the last decade various theoretical explanations have been proposed to explain this difference [see e.g. 4,5]. A possible difficulty with the method mentioned above is that all independent matrix elements that are involved in the decay need to be calculated, making the deduction of $\epsilon_{\rm MEC}$ susceptible to model assumptions.

Here, we report a new study of MEC in the ^{208}Pb region in which besides the ft-values, also the experimental β asymmetry parameters A_1 are used. By combining these two quantities, the rank 0 and rank 1 contributions in the decay can be separated. Because of this, only the rank 0 matrix elements have to be calculated to deduce $\epsilon_{\rm MEC}$ yielding its determination significantly less dependent on theoretical computations.

The β asymmetry experiments were performed by low-temperature nuclear orientation (LTNO) using cold on-line implantation at the NICOLE refrigerator on-line to ISOLDE at CERN and at the KOOL set-up on-line to LISOL in Louvain-la-Neuve. To reduce the influence of β scattering, β spectra were recorded with cooled (8 K) planar Ge detectors looking directly at the sample. Data were taken on the first-forbidden g.s. $\rightarrow$ g.s. transitions in ^{205}Hg $((\nu\mathrm{p}\frac{1}{2})^- \rightarrow (\pi\mathrm{s}\frac{1}{2})^+)$, ^{207,209}Tl $((\pi\mathrm{s}\frac{1}{2})^+ \rightarrow (\nu\mathrm{p}\frac{1}{2})^-)$, ^{209}Pb $((\nu\mathrm{g}\frac{9}{2})^+ \rightarrow (\pi\mathrm{h}\frac{9}{2})^-)$ and ^{213}Bi $((\pi\mathrm{h}\frac{9}{2})^- \rightarrow (\nu\mathrm{g}\frac{9}{2})^+)$. The different configurations of these nuclei allow a study of a possible state dependence of MEC. For each decay, the matrix element $\int\gamma_5$ was extracted using the newly measured A_1 parameters and known decay rate data. The new experimental data on $\epsilon_{\rm MEC}$ near ^{208}Pb will be compared with various MEC-calculations performed in the past decade [4-6] and discussed in view of the discrepancy between theory and experiment in this region [2-3].

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Isospin mixing in N $\approx$ Z nuclei

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Isospin impurities occur when nuclear states with $T \neq T_0$ are mixed into states with $T = T_0$. It is predominantly caused by the Coulomb interaction but possibly also by charge dependent terms in the nucleon nucleon interaction. In the N = Z region isospin mixing is enhanced because of the increased overlap between the neutron and proton wave functions. From an experimental point of view interest in isospin mixing has been triggered by the development of accelerated heavy ion beams and the production of doubly magic N = Z nucleus ^{100}Sn [1]. Here isopin mixing should increases because of the stronger Coulomb interaction in heavier nuclei. The understanding of isospin mixing is also important in tests of the Standard Model of electroweak interactions. Particular tests of the Conserved Vector Current (CVC) hypotheses and the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix use the $ft-$ values of the supperallowed $0^+ \rightarrow 0^+$ Fermi transitions which are subject to radiative (δ_R) and isospin-impurity (δ_c) corrections. Using data from [2] it is found that there is a deviation from unity by 2 to 2.3 σ, or that unitarity of the CKM matrix is excluded at the 95% confidence level [3]. A possible explanation for this situation might be found in an underestimation of the isospin mixing corrections δ_c in the determination of the dominant V_{ud} matrix element.

Theoretical calculations of $\Delta T = 1$ isospin mixing have been performed using the shell model with an empirical nucleon-nucleon interaction [4] and using the Hartree-Fock method with Random Phase Approximation [5-6]. Experimentally, isospin mixing in N $\approx$ Z can be determined by observing $E1$ γ decays or Fermi β transitions, both of which may vanish in the absence of isospin mixing. For $E1$ γ decay this is only the case when $N = Z$ ($T_0 = 0$). Fermi β decay on the other hand is also sensitive to isospin mixing when $T_0 \neq 0$ implying that also $N \approx Z$ nuclei can be investigated. Because isospin mixing is only appreciable in proton-rich nuclei, only β^+ decay is involved. By comparing the selection rules for allowed Fermi ($\Delta J = 0$; $\Delta T = 0$) and Gamow-Teller ($\Delta J = 0, 1$ ($0 \not\rightarrow 0$); $\Delta T = 0, 1$) β decay, it is clear that the observation of a Fermi component in a $J^\pi \rightarrow J^\pi$, $\Delta T = 1$ transition implies isospin mixing as the Fermi strength can only originate from a $\Delta T = 0$ contribution. In fact, the Fermi matrix element M_F directly yields the isospin mixing amplitude α.

Here we report on an experimental study of isospin mixing in the ground states of ^{52}Mn ($T = 1$) and ^{71}As ($T = 5/2$) via anisotropic positron emission from oriented nuclei. The β^+ asymmetry experiments were performed by low-temperature nuclear orientation. To reduce the influence of β scattering, β spectra were recorded with cooled (8 K) Si PIN diodes and planar Ge detectors looking directly at the sample. In addition, particular care was taken to ensure the purity of the radioactive sources. By combining the measured positron asymmetry parameter with the experimental $ft-$ value the magnitude of the isospin forbidden Fermi matrix element in the Gamow-Teller dominated β decay was determined. From that, the isospin mixing amplitude was deduced. Comparison with theoretical calculations show that the HF+RPA overestimate the isospin mixing probability by more than two orders of magnitude.

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Investigation of the Decay of Heavy Sn Nuclei using a Resonance Ionization Laser Ion Source*

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Recent studies on the decay of neutron-rich isotopes with A ~132, have been performed at the ISOLDE facility at CERN using a Resonance Ionization Laser Ion Source. The selectivity and ionization efficiency of this source has allowed for the study of Cu, Mn, Ag, Cd, and Sn neutron-rich species that are near subshell closure N=40 and shell closure N=82 [1,2,3]. The selectivity of the laser ionization source results from the specificity achieved from excitation and then ionization of desired products [4] that are produced from a 1 GeV proton-spallation of a UC_2 target. This ionization mechanism is accomplished by use of three dye lasers that are tuned specifically to electronic transitions of the desired products. By combining gamma, beta, and neutron spectroscopy, data were obtained for the half-lives and P_n values of ^{135,136,137}Sn. In addition, nuclear structure information was obtained for ^{135}Sb following the beta-decay of ^{135}Sn.

Heavy Sn nuclei, and all nuclei in the A~130 region are of both astrophysical and nuclear structure importance. Astrophysical ramifications involve trying to understand the mechanisms responsible for the r process abundance peak in the A~130 mass region. In order to perform accurate r-process calculations, precise measurements for β-decay half-lives, Q_β, S_n, and P_n are needed as far from the β-line of stability as possible. Improved results for r-process nucleosynthetic calculations have been obtained using β-decay half-life and P_n data for waiting point nuclei ^{129}Ag and ^{130}Cd [5].

The nuclear structure data obtained in this area is also of great interest because they allow for testing of the shell model for small numbers of particles or holes outside the Z=50 and N=82 shell closures of ^{132}Sn. Data on nuclei in this area are particularly important for comparison of microscopic nuclear-structure calculations. Studies of ^{133}Sn have already shown the difficulties of *ab initio* mean-field and HFB calculations to be able to account for the ordering and spacing of low-j orbitals [6]. The presence of low-energy $\nu p_{3/2}$ and $\nu p_{1/2}$ in ^{133}Sn, and other nuclei in various mass regions are attributed to monopole shifts of single-particle states. Theoretical studies show that this behavior can be accounted for by a reduction in the l^2 term in the Nilsson potential [7]. Other ambiguities in the theoretical models of nuclei in this region involve predictions for Gamow-Teller and first forbidden transition rates. These rates reveal important features of the structure of nuclei in the A~130 region, and also have serious implications on the development of accurate theoretical astrophysical computations. We report on the half-life and P_n values of heavy Sn nuclei and discuss the potential astrophysical and nuclear structure implications.

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Structure and Decay Properties of Heavy Zr and N = 82 r-Process Nuclides*

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The nuclear structure and decay properties of the neutron-rich nuclides with $38 \leq Z \leq 46$ with $N \leq 82$ play a critical role in determining the path of the r-process and the abundances of heavy isotopes in the A = 110 to 140 region. The most recent models for the masses of these nuclides exhibits a strong effect from the N = 82 closed shell, that, in turn, enhances the neutron capture rate relative to the photodisintegration rate for these nuclides. As a consequence of these enhanced neutron capture rates, the resulting abundances resulting from r-process calculations are found to be much lower than the observed abundances in this mass region. [1]

Subsequently, calculations derived using a reduced shell strength for the lighter N = 82 isotones showed much better agreement with the observed yields. In this paper, the monopole effects of single-particle levels for both protons and neutrons in this mass region will be discussed and the various possible sources of the shell quenching enumerated.

Finally, possible experiments that would assist in the testing of these ideas with advanced facilities will be presented and discussed.

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Decay properties of some transactinide nuclides studied with the OLGA technique

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The On-Line Gas chemistry Apparatus OLGA was applied to continuously separate transactinide elements and to analyze the products for correlated $\alpha - \alpha$ or $\alpha -$sf decay chains. This technique has a typical separation time of three seconds and an overall yield of about 10 %. This permits investigation of nuclides produced with cross sections as low as 10 pb [1].
^{18}O and ^{22}Ne beams were used to bombard ^{244}Pu, ^{248}Cm or ^{249}Bk targets at the PHILIPS cyclotron of PSI as well as the UNILAC accelerator at GSI in order to form evaporation residues mainly from the 4n and 5n channels.
Besides investigation of chemical properties, the OLGA device was applied to study nuclear decay properties of the nuclides ^{263}Db, ^{265,266}Sg and ^{266,267}Bh.
We will report on the measured decay properties of these nuclides that have half-lives between less than one second (^{266}Bh) and about 30 s (^{263}Db). They decay mainly via emission of α-particles and are clearly influenced by the neutron shell at N=162.
An improved version of OLGA, the IVO device (In-situ Volatilization and On-line detection) has recently been developed [2] that should give access to nuclear and chemical studies with nuclides (or elements) produced with cross sections as low as 1 pb. Two examples of future IVO applications to chemical investigation as well as nuclear decay studies will be outlined, the separation of hassium (element 108) in form of its very volatile tetroxide and of element 112 as very volatile noble metal.
Based on the high performance of OLGA or IVO set-ups such on-line chemistry separators might be well suited for future reaction studies at RIB facilities for product nuclides decaying via emission of α-particles or by spontaneous-fission.

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Probing the Structure of Exotic Nuclei by Advanced Time-Delayed Methods; Studies of μs Isomers at LISE in GANIL and RMS at HRIBF

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We have applied a novel time-delayed technique in order to determine lifetimes of the levels γ-fed from the exotic (and thus weakly populated) μs isomers. The measurements were performed at the LISE spectrometer in GANIL following fragmentation of the ^{76}Ge 60 MeV/u beam on a ^{9}Be target. An array of four BaF_2 detectors, which time response was precisely calibrated at the OSIRIS separator at Studsvik, was employed to search for level lifetimes from ~20 ns down to ~10 ps. The aim of the measurement was to verify theoretical structure interpretation of a few nuclei in a close vicinity of ^{70}Ni, via a strong pairing of $g_{9/2}$ neutrons. Several level lifetimes have been measured with high precision in ^{67,69,70}Ni and ^{71,72}Cu. Moreover, positions of gamma rays in the decay schemes have been also firmly assigned. The absolute transition rates provide a new level of information and more strict verification of the theoretical predictions. A preliminary result for the 694.1 keV level in ^{67}Ni is illustrated in Fig.1. A successful application of the BaF_2 array opens new possibilities for measurements of dynamic moments (via ps-lifetimes) in very exotic nuclei produced with very low intensity.

The N=Z=33 proton drip-line nucleus of ^{66}As represents one of the most interesting cases of μs isomers. Yet numerous experimental ambiguities in the knowledge of ^{66}As prevent a meaningful comparison with theoretical calculations. The time-delayed measurements, descibed above, could remove much of the existing ambiguities related to the postion of the γ rays in the decay scheme, level energies, spin/parities and the nature of the observed γ rays below the isomers. This should clarify the relative position of the low-lying T=0 and T=1 states crucial for the shell model interpretation of heavy N=Z nuclei. At present the most favourable conditions to perform the ATD measurements on ^{66}As exist at HRIBF at the Recoil Mass Separator (RMS).

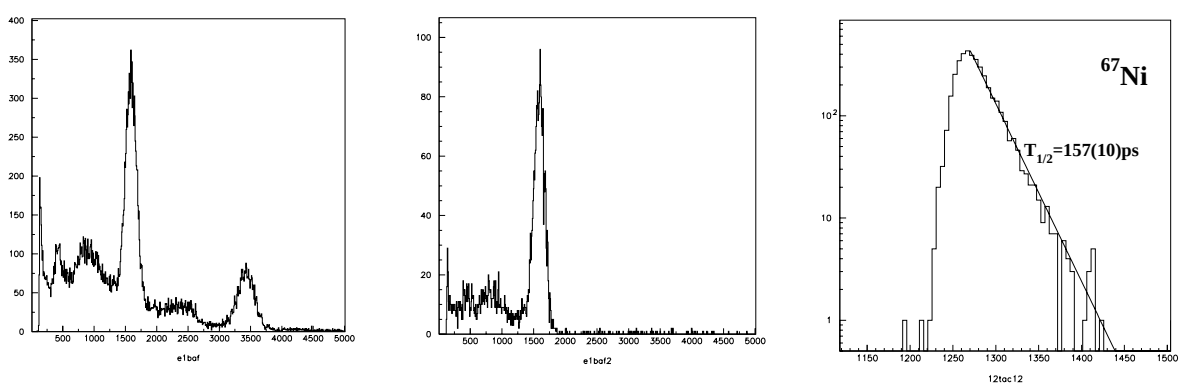
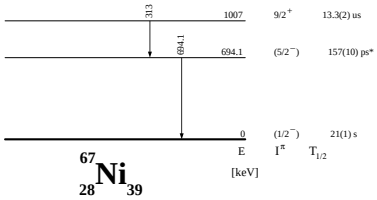


FIG.1. Left:The energy spectrum in BaF_2(det-1) showing the 313 (ch~ 1530) and 694 keV γ peaks (ch~3400). Middle: The coincident energy spectrum in BaF_2 (det-2) gated by the 694-keV γ-ray in BaF_2(det-1). The gate was set on the 694-keV full energy peak. Right: A time-delayed spectrum due to the 694-keV level in ^{67}Ni gated by the 313-keV (start) and 694-keV γ-rays (stop). Gates were set only on the full energy peaks.



Low Energy Tests of Fundamental Symmetries: Achievements and Prospects *

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The standard model of electroweak interactions contains a number of *ad-hoc* assumptions and poses a number of questions which are expected to find explanations in extended theoretical frameworks. There is a general consensus that, whatever the shape of the extended theory might be, new phenomena should manifest themselves either at the high energy frontier, which is accessible by exploring new energy domains, or at the precision frontier, which can be probed at any energy where precision measurements are possible.

It is well known that the nucleus is an attractive laboratory to perform precision experiments provided the involved decays are properly selected. The study of correlation observables in nuclear β-decay offer indeed simple means to perform sharp tests of the symmetry properties assumed by the standard model of electroweak interactions. More specifically, measurements of pseudoscalar observables, like the β-asymmetry parameter or the β-longitudinal polarization, and correlations involving an odd number of polar and axial vectors, constitute sensitive probes to search for deviations from maximal parity violation and from time reversal invariance in weak decays.

This paper will review such precision experiments which have made a significant progress over the past few years. In particular measurements combining the on-line production of an intense source of polarized nuclei with high efficiency polarimeters for the analysis of specific components of the β-polarization, have tested discrete space-time symmetries with unprecedent precision [1,2].

The prospects of measurements under preparation at several laboratories will be addressed with emphasis on the precision aims required by new experiments to improve present limits on non standard weak couplings.

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Spectroscopic studies of nuclei close to the proton drip-line in the region $Z = 30 - 38$

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During the last decade, several experiments aimed at studying neutron-deficient nuclei near or at the border of the proton drip line in the $Z = 30 - 38$ region. New isotopes were discovered and the proton drip line was indeed reached for odd-Z isotopes using projectile fragmentation [1-4] or fusion-evaporation reactions [5,6]. A recent experiment of ^{78}Kr projectile fragmentation, with the LISE (Line of Super Stripped Ions) spectrometer at GANIL [7], was performed to study spectroscopic properties of those very exotic nuclei :

1. decay of two isomers in ^{66}As [8] as well as β-decay half-life determination for some nuclei in this region [9]. These half-lives are important for the modelling of the astrophysical *rp* process and in particular for the isotope β-emitter ^{65}As, a key nucleus in the *rp* process ;
2. decay by β and $\beta\gamma$ emission of odd-odd $N = Z$ nuclei (^{62}Ga and ^{66}As), in order to determine, via their half-lives, the universal Ft value for superallowed Fermi transitions [10] ;
3. decay of $T_z = -1/2$ nuclei (^{67}Se and ^{71}Kr) by delayed βp emission to improve half-life and proton branching ratio measurements, as well as to seek for a ^{71}Kr isomer-to-be [11-14] ;
4. the very first measurement of half-lives and decay properties of ^{60}Ga and ^{64}As to find out if they are proton emitters (they would be then the lightest ones known to-date) or β emitters (which would open new paths for the *rp* process), and also obtain more accurate data on ^{61}Ga et ^{65}As,

the last results will be presented here.

The detection apparatus consisted of a silicon telescope, including a silicon strip detector (for x-y measurements) where the ions were implanted and their following decays observed while keeping track of the correlation between nuclei identification and radioactivity. High efficiency germanium detectors surrounded the silicon telescope.

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Rearrangements in Neutron Shell Closures of Very Neutron-Rich Nuclei

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The study of the properties of extremely neutron- or proton-rich nuclei of light elements is a very important topic in the modern nuclear physics. The research in this field has revealed a halo and skin structure and other unique features that could result in the modification of magic numbers in very neutron-rich nuclei. A breaking of magicity has already been observed at the N=20 shell closure where an "island of inversion" in shell ordering has been shown to exist. Though some theoretical calculations predict the existence of new magic number N=16 [1], until recently no experimental evidence about magic numbers, substituting N=20, was available. Recently, we have presented a review [2] of experimental results obtained at GANIL suggesting the appearance of new magic number, N=16, in this region. Our finding was based on the following experiments.

An experiment on the LISE3 spectrometer, where we used the fragmentation of the neutron-rich projectile ^{36}S to produce and study very neutron-rich nuclei in vicinity of doubly magic ^{28}O [3]. No events were observed corresponding to oxygen isotopes ^{25,26,27,28}O and also to ^{24,25}N. It should be noted that the instability of ^{25,26,27,28}O and ^{24,25}N was also confirmed by Sakurai et al. [4] where, however, a new isotope, ^{31}F, was observed for the first time. Thus the heaviest experimentaly found isotopes of C, N and O have the same neutron number, N=16, while the heaviest isotope of fluorine was found to be ^{31}F with N=22.

The question of particle stability is directly related to the masses and nuclear binding energies, which are very sensitive to the existence of shells and may provide clear signature of shell closures. Therefore, an experiment on the mass measurement using a direct time of flight technique [5] was undertaken in order to investigate the N=20 and 28 shell closures for nuclei from Ne to Ar and thus to shed some light on the behaviour of magic numbers far from stability.

The nuclei of interest were produced by the fragmentation of a 60 AMeV ^{48}Ca beam on a Ta target. The separation energies of two last neutrons S_{2n} derived from the measured masses were plotted versus neutron number. The Ca, K and Ar isotopes show a behaviour typical of the filling of shells, with the two shell closures at N_{sh}=20 and 28 being evidenced by the corresponding sharp decrease of the S_{2n} at these points, and a slowly decreasing S_{2n} after the "flattening" point N_f=(N_{sh}+2) as the filling of the next shell starts to influence S_{2n}. The "flattening" point of the slope at N_f=22, corresponding to the existence of the shell N_{sh}=20, is clearly visible for Si-Ca region, while going to lower Z into the Al-Na region this point seems to move towards to lower N till it stabilizes at N_f=18 (new shell N_{sh}=16) for F and Ne.

Thus the behaviour of the "flattening" points in the S_{2n} values gives a very clear evidence for the existence of the new shell closure N=16 for Z=9 and 10 appearing between $2s_{1/2}$ and $1d_{3/2}$ orbitals. This fact strongly supported by the instability of C, N and O isotopes with N > 16, found in refs. [3,4], confirms the magic character of N=16 for the region 6$\leq$ Z $\leq$10, while the shell closure at N=20 tends to disappear for 6$\leq$ Z $\leq$13. This is in a good agreement with recently published work of Ozawa et al. [6] where the similar information on the magicity of N=16 was obtained from S_{1n} values and σ_I.

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Two-proton radioactivity as a genuine three-particle decay: the ^{19}Mg probe.

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Two-proton emission, the specific case of three-particle decays, may be described by two complementary mechanisms: the sequential emission of protons via an intermediate state, and the simultaneous, or direct, emission of protons. The first mechanism includes also the model of emission of "diproton", or a ^{2}He cluster with very strong *pp*-correlations. This model is traditionally associated with the two-proton radioactivity, [1], which is unobserved yet.

In the Ref. [2], a two-proton emission has been considered for the first time in a realistic three-body model. This approach is suitable for treatment of a genuine three-particle decay, where resonances in the binary subsystems are located at higher energies than in the three-body system, and the emission process is non-sequential. This situation is similar to the "borromean" property of bound halo nuclei (e.g. ^{6}He, ^{11}Li, ^{17}Ne). Genuine three-body decay modes are known for several states in light nuclei, e.g. ^{6}Be [3], ^{9}Be* [4], ^{12}C* at 15.11 MeV [5]. The model is applied to candidates for the two-proton radioactivity, the ^{19}Mg and recently discovered ^{48}Ni [6], which are likely to be bound to single proton decay but unbound to two-proton decay.

The results of the calculations predict 1000 times larger life-times of ^{19}Mg and ^{48}Ni than the traditional diproton model, e.g. up to 100 ps for ^{19}Mg. Specific observable, p-p correlations following the ^{19}Mg decay, differ drastically in predictions of these models as well. The strong *pp*-correlations which exist in the interior of the nuclei are significantly smoothed in asymptotic by the proton pairing and Coulomb interactions.

We discuss the comprehensive experiment, in which a possible radioactivity of ^{19}Mg might be studied as its decay in flight by invariant mass method detecting all three fragments in the ^{17}Ne+p+p coincidences. The specific *pp*-correlations as well as mass excess and life-time of the ground state of ^{19}Mg can then be obtained. The ^{19}Mg life-time may be derived from the measured decay vertex distribution. Then a precise determination of all fragment trajectories is needed that can be achieved by microstrip detectors. We show that such an experiment could be performed using the radioactive beam of ^{20}Mg, [7].

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Levels scheme of ^{147}Eu

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In presents work the energies and relative intensities of gamma rays, k conversional electrons and X_k-rays have been determined with high accuracy. Also multipoles of the following transitions were defined: 297,02(M1,E2); 341,31(E1); 346,28(M1); 506,59(M1,E2); 529,95(M1,E2); 882,09(M1,E2); 983,41(E1); 1399,25(M1,E2); 1676,33 keV (M1,E2).

As a results of analysis of the spectra of positrons two components $E_{\beta_1^+} = 1160(13)$ and $E_{\beta_2^+} = 933(5)$ keV have been given off. At this point $Q_{\beta^+} = 2185(5)$ keV. The new coincidences of K 229,29 with transitions: γ778,04, γ1232,76, γ1566,34, γ1586,80 and γ1676,33 keV were observed.

The spectra of gamma rays, internal conversion electrons (IWC), positrons and eγ-coincidences have been analysed and on this base the $^{147}Gd \rightarrow {}^{147}Eu$ decay scheme was constructed. New levels were introduced in the decay scheme: 1007,40; 1337,70; 1771,94; 1816,06; 1816,46; 1838,82; 1874,69; 1905,05 and 1965,64 keV.

The existence of this levels, which were introduced earlier by assumption, is proved by the analyses of eγ-coincidences. The quantum characteristics (I^{π}) of level 1474,57 keV were determined. In work the levels scheme of ^{147}Eu is discussed in detail.

PROPERTIES OF SAMARIUM (A=145,147,149) ODD ISOTOPES NUCLEI

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Values of spins of main states (I=7/2) in accordance with the cover model can be interpreted as states of odd neutron $2f_{7/2}$. An analysis of main and low located excited levels of samarium odd-neutron nuclei with N=83,85 and 87 shows that the levels $3/2^-$ of N=83 nuclei are located higher than those for N=85 nuclei. Analogous behavior is observed for states $5/2^-$ while transition from N=85 nuclei to N=87 ones.

^{145}Sm nucleus has one neutron over filled N=82 cover. The energy of first excited state has high value (893,74 keV, $3/2^-$). Calculations using single-particle model well describe characteristics of the following states: 0 keV ($2f_{7/2}$), 893,74 keV ($3p_{1/2}$) and 1423,22 keV ($1h_{9/2}$) in ^{145}Sm.

^{147}Sm nucleus has three neutrons over a closed cover. The energy of first excited state 121,25 keV ($5/2^-$) is abruptly decreased.

^{149}Sm nucleus has five neutrons over filled N=82 cover. First excited level of ^{149}Sm ($5/2^-$) is analogous to corresponding level of ^{147}Sm ($5/2^-$). The following levels 277,08 keV ($5/2^-$) and 350,00 keV ($3/2^-$) of the ^{149}Sm, probably, have multi-particle configuration. Values of lgft of corresponding β-transitions to these levels (8,4 and 8,2) allow one to make a conclusion that their wave-functions contain admixtures of a state which is described by $1h_{9/2}$ orbit, β-transition to the last is forbidden in accordance with l quantum number.

Even-even spanning set of ^{149}Sm is a nuclid of ^{148}Sm, which is soft for surface vibrations. That's why level 528,48 keV ($3/2^-$), probably, in accordance with quasiparticle-phonon model has the admixture of quasiparticle components in sub-covers $f_{7/2}$, $f_{5/2}$ (these levels are energetically close) plus phonon $Q_1(2)$.

It is difficult to tell anything concrete about property of 558,41 keV ($5/2^-$) level. Values of lgft for β-transition to this state point out to either multiparticle configuration with strong component of $h_{9/2}$ orbit, or appearance of noticeable deformation.

As a whole, the model rather well describes the structure of levels for these nuclei.

PROPORTIES OF ODD ISTOPE ^{147}Eu NUCLEUS

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Spectra of γ-rays and electrons of internal Conversion (EIC) in the process of ^{147}Gd → ^{147}Eu decay have been investigated. A number of new unsufficiently intensive gamma-transitions was revealed, and they were placed into the decay scheme:

Gamma-transitions of ^{147}Eu

In previous papers the basic experimental results, connected with the investigation of K_x-, γ-radiation, electrons of internal conversion (EIC) and spectra of positrons (β^+) were published.

The present paper reports on new data and analysis of spectra of γ-rays, EIC and positrons. There revealed a number of new unsufficiently intensive γ-transitions, and a part of them is placed into the scheme of ^{147}Gd → ^{147}Eu decay.

Experimental values of the coefficient of internal conversion (CIC) were compared with the theoretical calculations, and multiplicities of ^{147}Eu γ-transitions were identified. In the process of calculation of an error in determination of a relative intensity of K-conversion electrons, gamma-rays, and a coefficient of scale connection. As a result, we determined the multiplicities of the following unsufficiently intensive transitions:

E_γ (ΔE_γ), keV	I_γ (ΔI_γ)	I_k (ΔI_k)	α_k ($\Delta\alpha_k$)	σL	E_i	E_f
	arb. units					
537,68(8)	0,15(3)	-	-	-	-	-
548,78(6)	0,14(2)	0,018(5)	0,019(6)	M1,E2	-	-
647,01(1)	0,12(2)	-	-	-	-	-
737,45(12)	0,10(1)	0,003(1)	0,045	M1,E2	1806,55	1069,246
751,81(13)	0,28(4)	0,024(7)	0,013(4)	M1	1874,69	1122,714
834,58(6)	0,021(7)	-	-	-	1696,30	861,640
918,15(24)	0,07(2)	-	-	-	-	-
936,98(23)	0,06(1)	-	-	-	-	-
948,29(5)	0,16(1)	-	-	-	-	-
976,8(3)	0,042(8)	-	-	-	1838,82	861,646
1017,85(4)	0,18(1)	-	-	-	-	-

The obtained results are original. In this paper we discuss the quantum characteristics of the excited states of ^{147}Eu nucleus.

A Digital Spectroscopy System for Charged Particle Studies at the RMS

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We have installed and commissioned a digital flash ADC electronics system for proton decay studies using the Double Sided Strip Detector (DSSD). This new system is based on the Digital Gamma Finder (DGF-4C) units produced by X-ray Instrumentation Associates (XIA) [1]. This system involves fitting the preamp signals via the on-board processors. The signal from the high energy recoil takes several tens of μsec to fall to the baseline, fast decays will then appear as a small "pileup" signal on top of the larger signal. By fitting the two signals, we are able to observe decays within ~500 nsec of implantation with a low-energy threshold of less than 300 keV.

Two modes of operation have been developed for the acquisition: "Standard Mode" and "Proton Catcher Mode". In the standard mode, signals from the preamps are analyzed and time stamped by the processors contained in the modules. Each event contains the energy amplitude of the signal and the time when it occurred. The proton catcher mode accepts only those events that occur within 10 μs of each other. In this mode, the processors record the entire signal waveform, which contains both the first (larger) recoil signal , and the second (smaller) decay signal lying on top of it.

The "proton catcher" mode has been used in several searches for short-lived proton emitters, and fine structure studies of ^{145}Tm [2]. The use of our new digital system has resulted in an order of magnitude gain in the rate for this short-lived isotope (3 μs) over previous work [2] performed at the Holifield facility.

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