HIGH-SPIN STRUCTURE OF ^{57}Ni AND NUCLEI NEARBY* **

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Nuclei, ^{57}Ni, ^{58}Ni, ^{57}Co, from the closest vicinity of doubly magic ^{56}Ni have been investigated in a series of in-beam γ-spectroscopy measurements. New experimental results concerning the structure of ^{57}Ni are discussed in details. The observed excitations are qualitatively interpreted in the frame of shell model.

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Although the nuclei around doubly magic ^{56}Ni have been heavily investigated up to now, due to their importance for the shell model theory, the region, specially the nuclei from the closest vicinity of ^{56}Ni, is still not enough explored both from the experimental and the theoretical points of view. The situation, however, is changing as a number of new investigations has been reported very recently. We also have performed a series of in-beam γ-spectroscopy measurements aimed to study excitations in nuclei from that region.

In the first experiment performed in HMI Berlin, the 68 MeV ^{20}Ne pulsed beam from VICKSI accelerator bombarded 1.0 mg/cm^2 ^{40}Ca selfsupporting target, populating ^{57}Ni-nucleus via (^{20}Ne,2pn)-reaction. The experimental

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setup consisted of the OSIRIS γ-detecting system and the Recoil Filter Detector (RFD) [1]. In this case, where fusion-evaporation dominates, the main role of the RFD was to enable a precise event-by-event Doppler-correction of the observed γ-lines. These data were also used to construct the DCO-matrix, where coincidence events from 5 detectors placed at 25° and 38° were sorted against those from the other 5 detectors at 63° and 90°.

In the second experiment performed in LNL-Legnaro, we used (^{28}Si + ^{32}S)-reaction leading to the same compound nucleus. Targets in chemical form of ZnS and with the thickness of 0.5 mg/cm^2 were prepared on both a thin (1 mg/cm^2) and a thick (10 mg/cm^2) Au-backings and bombarded with 84 MeV ^{28}Si-beam in two independent measurements. The detection system employed the GASP γ-spectrometer and ISIS array. The DCO-matrix from this experiment contained events from detectors at 90° versus those at 36° and 144°.

The ^{57}Ni nucleus was previously investigated in many experiments [2], but almost exclusively light particle induced reactions were employed. Only a few of the measurements were performed using γ-spectroscopy methods. Thus very little was known about high spin levels and γ-deexcitation in ^{57}Ni. When starting, our study the known yrast structure was limited to only three states [3]: $7/2^-$ at 2577 keV, $11/2^-$ at 3865 keV and $15/2^-$ at 5320 keV, depopulated by three γ-transitions of 2577.5 keV, 1287.6 keV and 1455.1 keV respectively. Our coincidence spectra gated on these transitions revealed many new γ-rays confidently assigned to ^{57}Ni. Detailed analysis of the spectra identified higher lying states extending the ^{57}Ni level scheme up to 9.5 MeV. The observed γ-γ coincidence relations established also many non-yrast states and their complicated decay mode. The deduced scheme of ^{57}Ni excitations is presented in Fig. 1.

Several weak transitions observed in coincidence spectra are not included into the level scheme. Two transitions, 734 keV and 1057 keV, are most probably located above 7815 keV level feeding it directly. A cascade of 1722 keV and 1614 keV γ-rays connects levels at 7039 keV and 3702 keV. The other two transitions, 723 keV and 1629 keV, depopulate probably the same level at 7144 keV. All these γ-rays are very weak in ^{57}Ni deexcitation. Moreover, there are much stronger transitions of similar energies in other reaction products, therefore, γ-coincidence spectra gated on them are not conclusive and consequently their firm placement in ^{57}Ni level scheme cannot be established.

In order to get the spin assignment of the levels, the DCO-matrices from both experiments were analysed with a special care. For a pair of transitions, γ_1 - γ_2, two values of DCO-factor were usually extracted. One was defined as a ratio of γ_2-intensities, $I_{\gamma_2}^{"30"}/I_{\gamma_2}^{"90"}$, observed in DCO-spectra gated on the γ_1-transition. The second one was obtained from the spectra

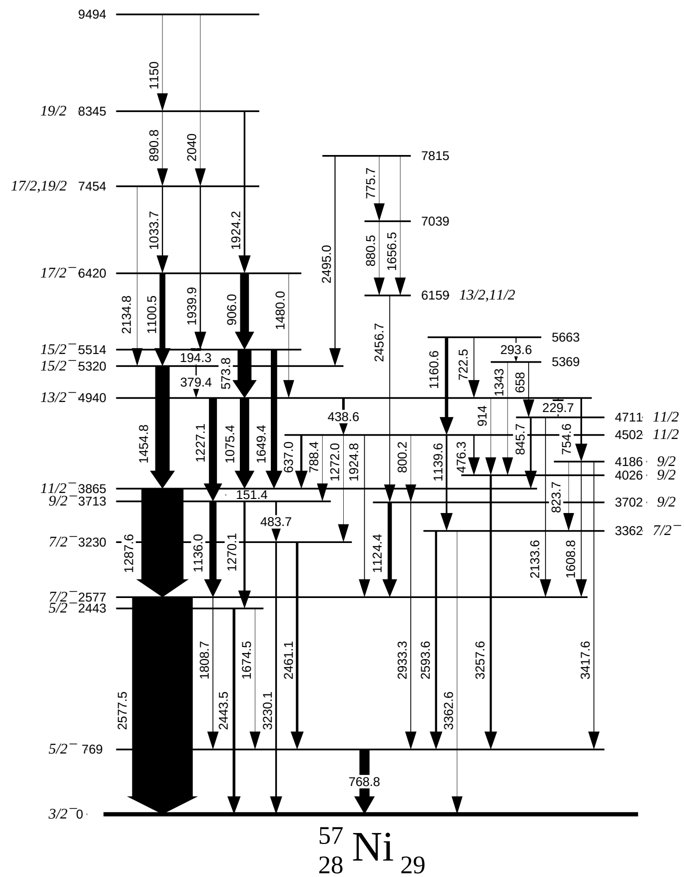

Fig. 1. The level scheme of ^{57}Ni as deduced from our experiments

gated on the γ_2-transition and calculated as the intensity ratio of the γ_1-line, $I_{\gamma_1}^{"90"}/I_{\gamma_1}^{"30"}$. The mean value of both gives the measured $R_{\rm DCO}^{\rm exp}$-ratio for the γ_1–γ_2 combination. The experimental errors were estimated as 10% for the strong transitions and up to 25% for the weak γ-rays.

The experimental $R_{\rm DCO}^{\rm exp}$-ratios were compared with the theoretical values calculated with the improved version of the program developed by Krämer-Flecken [4]. In most cases the $R_{\rm DCO}^{\rm exp}$-ratio could be reproduced by several $R_{\rm DCO}^{\rm th}$-values calculated for different spin combinations and appropriate δ-transition mixing ratios. Therefore an additional information was needed to extract unique spin assignment for the individual level. In our DCO-analyses we have used the E2-character of the three lowest yrast transitions [3]. Furthermore, we were helped by the fact that each state branches to several other levels which ruled out some of the possibilities. Also the rigorous requirement of the consistency of all our results eliminated some of the ambiguities. This analyses of the big number of $R^{\rm exp}_{\rm DCO}$-ratios for many possible γ_1–γ_2 combinations resulted in unique spin assignments of almost all states.

The big $R^{\rm exp}_{\rm DCO}$-values for the 1100.5 keV γ-ray paired with each of the yrast transitions exclude its $\Delta I = 2$ and $\Delta I = 0$ nature and thus determine the spin $I = 17/2$ for the 6420 keV yrast state. The spin of the 7454 keV level cannot be firmly established, since from the DCO-results the 1033.7 keV transition can be interpreted as $\Delta I = 0$ as well as $\Delta I = 1$ transition and the other two branches are too weak in our data to extract their $R^{\rm exp}_{\rm DCO}$-ratios. The spin assignment $I = 19/2$ for 8345 keV level is based on two DCO-ratios involving 1924.2 keV transition depopulating this state, namely: $R^{\rm exp}_{\rm DCO}(1924–906) = 1.22(20)$ and $R^{\rm exp}_{\rm DCO}(1924–1287) = 1.28(25)$. The theoretical values calculated with the initial spin $I = 19/2$ and $\delta(1924) = 0.1$ are $R^{\rm th}_{\rm DCO} = 1.215$ and 1.373, whereas the assumption of the initial spin $I = 21/2$ would give $R^{\rm th}_{\rm DCO} = 0.878$ and 0.999, respectively. Intensity of the second γ-ray depopulating this level is too small and therefore DCO-results cannot conclusively support our spin assignment. Also the spin of the highest lying excitation remains undefined because of insufficient statistics of the depopulating transitions. Much higher statistics was collected in (^{28}Si+^{32}S)-experiment, but these DCO-data can be used only for the spin determination of the states with longer half life, where Doppler-effect does not influence the shape of depopulating transitions. The spins of almost all intermediate levels below 5.6 MeV were established primarily from that measurement.

Detailed theoretical interpretation of the observed excitations in ^{57}Ni is not possible without the advanced large scale shell model calculations. Qualitatively, one can understand the character of the lowest lying yrast levels comparing them to the known excitations of the ^{56}Ni core nucleus [5]. The coupling of the valence neutron from the $\nu {\rm p}_{3/2}$ or $\nu {\rm f}_{5/2}$ shell to the 2^+, 4^+ and 6^+ levels of the core forms the negative parity multiplets up to maximum spin $17/2^-$. The structure of higher lying yrast states can involve the high spin (8^+) and (10^+) excitations together with the $p_{3/2}$ or $f_{5/2}$-neutron. An alternative possibility of their interpretation may be the coupling of the neutron from the high-j $g_{9/2}$-orbital to the 6^+ excitation of ^{56}Ni giving the multiplet of positive parity states. Lacking information on the single $\nu g_{9/2}$ energy and the level parities prevents any further, even such qualitative conclusions on the structure of the states above 7 MeV.

In the ^{57}Ni nucleus one can expect the level of $\nu g_{9/2}$ character in the energy region 3.5–4.5 MeV, because it should lie somewhat higher then analogous 3054 keV state in ^{59}Ni [6] and have not very different energy as the level at 3510 keV in ^{57}Cu [7], which can be interpreted as a $\pi g_{9/2}$ single particle state. Our data identified three levels with the spin 9/2 above 3.5 MeV. It seems that the best candidate for the $\nu g_{9/2}$ excitation is the state at 3701 keV. Although its parity was not defined from the experiment, the special features of that level allow to speculate about its nature. The first intuitive argument comes from the inspection of the level structure observed above this state. The level sequence resembles the shell model coupling to the 2^+ and 4^+ excitations of the core as expected above single particle state. The special character of the 3701 keV level is also shown by the fact of its direct population via proton decay from the $(\pi g_{9/2}\nu g_{9/2})$-deformed band in ^{58}Cu, recently reported in Ref. [8]. The suggested interpretation of 3701 keV level has to be confirmed by the theoretical calculations.

The reactions used in our experiments populated several other nuclei in the ^{56}Ni region with sufficient cross sections to investigate their structure. From the analysis of the data we obtained preliminary results on the excitations in ^{58}Ni expanding the known level scheme up to 9 MeV. The most complete information collected from our measurements concerns the structure of ^{57}Co-nucleus. High spin levels identified up to 11.3 MeV revealed very complicated decay pattern. The life time for many of these states was measured using the DSA-method. Its low spin excitations were investigated also in an additional experiment performed in IFJ-Kraków, where ^{57}Co-nucleus was produced in ^{55}Mn(α,2n)-reaction.

Summarizing, we have obtained experimental results offering new and needed information on the structure of nuclei from the closest vicinity of ^{56}Ni. Their detailed interpretation, however, needs advanced shell model calculations.

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