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Evidence for an isomer in ^{76}Ni

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Abstract. In the experiment performed at the LISE2000 spectrometer at GANIL neutron-rich nickel isotopes were studied by microsecond isomer spectroscopy. Evidence for an isomer in ^{76}Ni is found, consistently with the shell model prediction of an 8^+ state of $\nu(g_{9/2})^2$ structure.

PACS. 23.20.Lv γ transitions and level energies – 27.50.+e $59 \leq A \leq 89$

Neutron-rich nuclei, situated far from the line of beta-stability, have gained recently an increased interest. According to theoretical predictions, traditional shell gaps and magic numbers may no longer be valid for nuclei with an extreme N/Z ratio [1]. Of particular interest are nuclei in the vicinity of $^{78}_{28}$Ni$_{50}$ which is expected to be a waiting point in the astrophysical r-process, provided it is the doubly magic system.

On the other hand, a considerable progress in accessing experimentally new regions on the neutron-rich side of the chart of nuclei has been observed in the last years. A combination of projectile fragmentation-like reactions with the magnetic separation and in-flight identification of individual ions has emerged as one of the most promising techniques. Indeed, the first observation of ^{78}Ni itself [2] was one of the spectacular examples of this method. However, experimental information on the energy levels and lifetimes around ^{78}Ni is still very scarce. The pioneering experiments of Grzywacz *et al.* [3,4], devoted to studies of microsecond isomers produced in the fragmentation of a ^{86}Kr beam, which combined identification sensitivity of heavy ions with high-efficiency and high-resolution gamma spectroscopy, revealed that the low-energy structure of neutron-rich nuclei beyond ^{68}Ni is governed by the $\nu g_{9/2}$ orbital giving rise to $I^\pi = 8^+$ isomers. An example is the 8^+, $T_{1/2} = 226(3)$ ns isomer in ^{70}Ni of $(\nu g_{9/2})^2$ character. In a subsequent study, with an improved experimental set-up, evidence for the 8^+ isomer in ^{78}Zn has been obtained [5], establishing this nucleus as the closest one to ^{78}Ni with known excited states, and suggesting the persistence of $N = 50$ shell closure. In contrast, no evidence for expected 8^+ isomers of similar structure in ^{72}Ni and ^{74}Ni was found.

Motivated by this puzzle of $\nu g^n_{9/2}$ structure in the vicinity of ^{78}Ni, and encouraged by the upgrade of the LISE spectrometer at GANIL (LISE2000) offering higher rates of exotic reaction products, as well as availability of large-volume Ge detectors from the EXOGAM array, we undertook again a study of neutron-rich nickel isotopes. In parallel to microsecond isomer spectroscopy, β decay studies of cobalt isotopes were carried out as an alternative approach to access excited states in the daughter nickel nuclei. The full description of the experiment and of all results obtained will be published separately. Here, we report briefly on a particular result of this study —an evidence for a microsecond isomer in ^{76}Ni.

Ions of interest were produced by the fragmentation of a ^{86}Kr beam at an energy of 58 MeV/nucleon and a

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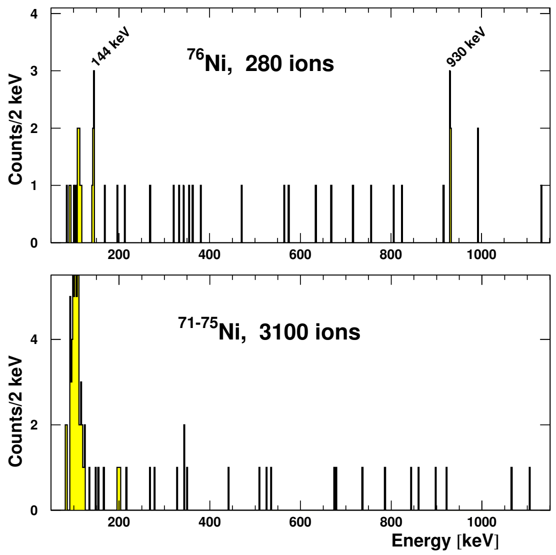

Fig. 1. Gamma spectrum correlated with ^{76}Ni ions (upper part), and with ions of ^{71,72,73,75}Ni (lower part). In both spectra γ events occurring up to 2 μs after implantation (including prompt radiation) are shown.

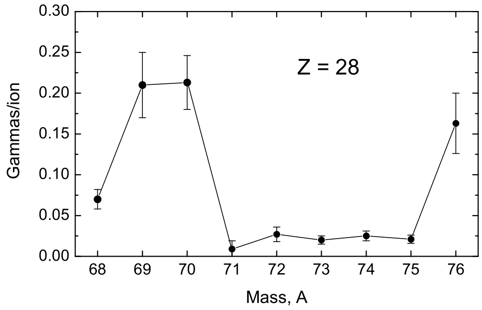

Fig. 2. The number of γ-rays per ion for nickel isotopes measured in the experiment.

mean intensity of 80 pnA impinging on a rotating ^{nat}Ta target of 30 μm thickness mounted at the entrance of the LISE2000 spectrometer. Behind the target a 125 μm thick carbon stripper was used. In order to achieve the highest sensitivity for short-lived isomers, the detector set-up was mounted in the first achromatic point of LISE, only 19 m downstream from the target. As a result, the typical time of flight (TOF) was less then 200 ns. The implantation set-up consisted of four silicon detectors of 300 μm, 500 μm, 1 mm, and 3.5 mm thickness, respectively. Selected ions, after passing through the first two detectors, which delivered energy loss information, were finally stopped in the third one which served for the residual kinetic-energy measurement. The fourth detector acted as a veto counter for heavy ions and as a beta detector. The silicon telescope was surrounded by four clover-type EXOGAM Ge detectors. The total full-energy peak efficiency of the array was found to be 6% at 1.3 MeV and 23% at the maximum around 120 keV. Timing signals from the first Si detector were used to measure the TOF with respect to the HF signal of the cyclotron as well as to trigger the data acquisition system. Determination of energy loss, total kinetic energy and TOF, allowed the unambiguous identification of mass A, atomic number Z and charge q of each stopped heavy ion. Decays and lifetimes of isomeric states were measured by recording heavy-ion identification signals and delayed γ-rays in the same event of data acquisition. Delay time between ion implantation and γ-ray detection was measured using standard time-to-digital converter (TDC) and time-to-amplitude converter (TAC) modules in a time range of up to 8 μs and 80 μs, respectively.

In the measurement, lasting about 100 hours, 280 ions of ^{76}Ni were stopped in the Si telescope. The spectrum of γ events, correlated with implantation of ^{76}Ni and summed over all Ge detectors, is shown in the upper part of fig. 1. Despite very low statistics two weak peaks emerge, at 144 keV (6 counts) and at 930 keV (5 counts), which may represent gamma transitions from an isomer in ^{76}Ni. Decay time analysis of these events yields a half-life $T_{1/2} = 240 \pm 80$ ns. To illustrate the contribution from background radiation, we plot in the lower part of fig. 1 the spectrum of γ events correlated with 3095 ions of ^{71,72,73,75}Ni in which no isomers are populated. The same time conditions were applied to both spectra. From the lower spectrum it follows that the probability of detecting one background count in a 4 keV bin, per one heavy ion, is lower than 5×10^{-5}. Thus, the probability that 5 background counts appear randomly at the position of 930 keV peak for 300 ions is lower than 10^{-9}. Another argument in favor of isomerism in ^{76}Ni can be derived from the total number of γ-rays related to the number of heavy ions. Figure 2 shows the ratio of the number of all γ-rays with energies above 100 keV and occurring between 0.1 μs and 2 μs after implantation to the number of implanted ions for nickel isotopes measured in the experiment. This ratio for ^{76}Ni is significantly larger than for lighter Ni isotopes except for ^{69}Ni and ^{70}Ni which do contain isomers populated in our reaction [4]. The gammas/ion ratio depends on the isomer population probability, on its half-life and on the decay pattern. The deduced half-life of 240 ns, attributed to the decay of ^{76m}Ni is close to that of ^{70m}Ni. Moreover, the 8^+ isomer in ^{76}Ni is expected to have a similar population probability and the same decay pattern as the isomer in ^{70}Ni. Thus, the fact that the values of gammas/ion ratio for ^{76}Ni and for ^{70}Ni are close is consistent with the assumption that the γ events associated with the implantation of ^{76}Ni do represent the decay of the 8^+ isomer in this nucleus.

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