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Short Note

Beta decay of ^{50}Ni

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Abstract. The very neutron-deficient isotope ^{50}Ni was produced in fragmentation reactions between a $650 \cdot$ A MeV ^{58}Ni beam and a ^{9}Be target. For the first time the decay of this nucleus was investigated, leading to the determination of the half-life as 12^{+3}_{-2} ms and the branching ratio for β-delayed proton emission of (70 ± 20)%.

PACS. 21.10.Tg Properties of nuclei; nuclear energy levels: Lifetimes – 23.40.-s β decay; double β decay; electron and muon capture – 29.30.Ep Charged-particle spectroscopy

Nuclei close to the proton drip line in the mass region between $A = 40$ and $A = 50$ are the subject of extensive investigations. The aim of these studies is, firstly, to produce nuclei which are considered to be suitable candidates for two-proton ground-state (2p) decay, such as ^{48}Ni, ^{45}Fe and ^{54}Zn [1–3]. Recently, the first evidence for 2p decay of ^{45}Fe [4,5] was reported. A second motivation for experiments in this mass region is to probe nuclear structure by determining other decay properties. The spectroscopic properties of these proton drip line nuclei, including ^{50}Ni, are important, *e.g.*, in the framework of atomic-mass determinations and of modelling the astrophysical rp-process.

^{50}Ni was first identified a few years ago as a product of a fragmentation reaction [6]. Its production cross-section was measured, whereas no spectroscopic information such as half-life or decay mode was established. In this note we report on the first spectroscopic investigation of ^{50}Ni.

The isotope ^{50}Ni was produced by relativistic fragmentation reactions induced by a ^{58}Ni beam at $650 \cdot$ A MeV impinging on a 4 g/cm^2 thick ^{9}Be target, and separated by means of the Projectile Fragment Separator (FRS) [7] at GSI. The average ^{58}Ni beam intensity amounted to $4 \cdot 10^9$ ions/spill, each spill being 2 s long with a repetition period of 7.6 s. The total measuring time was 36 hours.

The identification of the fragments was accomplished by determining their nuclear charge as well as the ratio between their mass and ionic charge state [4]. In order to get an unambiguous identification, *i.e.* to suppress background events originating from reaction products closer to the β-stability line, the time of flight was measured between the third and fourth focal plane of the FRS, additionally to determining it in the normal way, *i.e.* between the second and fourth focal plane. At the final FRS focus, the fragments were implanted into a telescope of 8 silicon detectors, each 300 μm thick and 60 mm in diameter. The energy resolution of the sum of the energy signals from all the detectors amounted to 250 keV for

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1.98 MeV β-delayed protons (βp) [8]. The implantation of such energetic ions leads to saturation of standard preamplifiers for a few hundred microseconds. In order to overcome this problem, a new type of preamplifier has been developed [8]. It is "blocked" for 2 μs at the beginning of the implantation. In this way the large charge generated by the implantation does not overload the preamplifier which thus can still have the large amplification required for spectroscopy studies. A detailed description of both the FRS and spectroscopy detector set-ups is given in refs. [4,8]. Two independent data acquisition systems were employed to process and store the data, one based on conventional pulse-shaping electronics and the other one on digital spectroscopy [8]. This note includes only the results from the analysis of the data collected by means of the conventional electronics.

The isotope ^{50}Ni is the heaviest $T_z = -3$ nucleus observed to date. It is particle bound, as predicted by most mass models and systematics, and as experimentally verified by Blank *et al.* [6]. The S_{p} and $S_{2\mathrm{p}}$ values of ^{50}Ni are predicted to be 1500 keV [9] or 730 keV [10], and 260 keV [9] or 300 keV [10], respectively. Thus, the only disintegration mode of ^{50}Ni is expected to be β^+/EC decay, with an estimated Q_{EC} value and half-life of 13400 keV [9] or 14600 keV [10] and 16.8 ms [10], respectively. By evaluating the Coulomb energy difference (ΔE_{C}) for ^{50}Ni-^{50}Co, the energy (E_{IAS}) of the $T = 3$, 0^+ isobaric analogue state (IAS) in ^{50}Co can be estimated. Assuming that the parametrization of ΔE_{C} given for $T = 2$ in [11] remains valid also for $T = 3$, $\Delta E_{\mathrm{C}}(^{50}\mathrm{Ni}\text{-}^{50}\mathrm{Co})$ is found to be 9630 keV, corresponding to $E_{\mathrm{IAS}}(^{50}\mathrm{Co}) = 3770$ keV. The spin and parity of the ^{50}Co ground state can be estimated to be (6^+) from the corresponding properties of the mirror nucleus ^{50}V [12]. Considering that the ground state of ^{50}Ni has spin and parity 0^+, its allowed β-decay will feed only the IAS and 1^+ states in ^{50}Co, thus excluding decay to its ground state. From a comparison with the known level scheme of the mirror nucleus ^{50}V [12], a few 1^+ levels close to the estimated IAS in ^{50}Co are expected to be populated by Gamow-Teller transitions. Since ^{50}Co is predicted to be proton unbound by (90 ± 230) keV [9] and two-proton bound by (2.8 ± 0.2) MeV [9], all the levels populated in ^{50}Ni decay will promptly emit one or two protons. Thus, one expects a branching ratio of the order of 100% for βp or β2p decay of the 0^+ ground state of ^{50}Ni. The spin and parity of the ground state and first excited states of the βp daughter of ^{50}Ni, ^{49}Fe, can be estimated from the relevant properties of its mirror nucleus ^{49}V [13]: $(7/2^-)$, ground state; $(5/2^-)$, 90 keV; $(3/2^-)$, 153 keV; $(3/2^+)$, 748 keV. This scenario is schematically summarized in fig. 1. In the following we do not consider the β2p process. This approximation is based on the fact that for a given ^{50}Co excitation energy β2p emission is, due to energy and angular-momentum considerations, hindered compared to βp emission. The latter argument is based on the assumption that the β2p daughter of ^{50}Ni, ^{48}Mn has a (4^+) ground state [14] and a first excited state of (1^+) assignment at 420 keV [15].

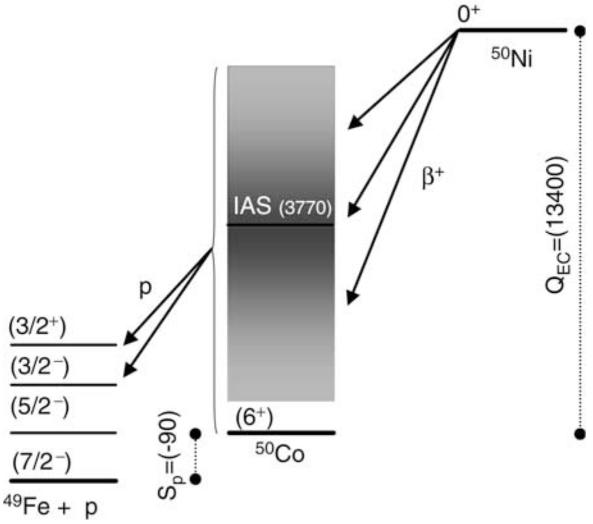

Fig. 1. Sketch of the ^{50}Ni decay scheme. The Q_{EC} and S_{p} values stem from extrapolations of systematical trends [9], whereas Coulomb displacement energy systematics [11] were used to estimate the IAS energy in ^{50}Co. All energies are given in keV, but are not drawn to scale.

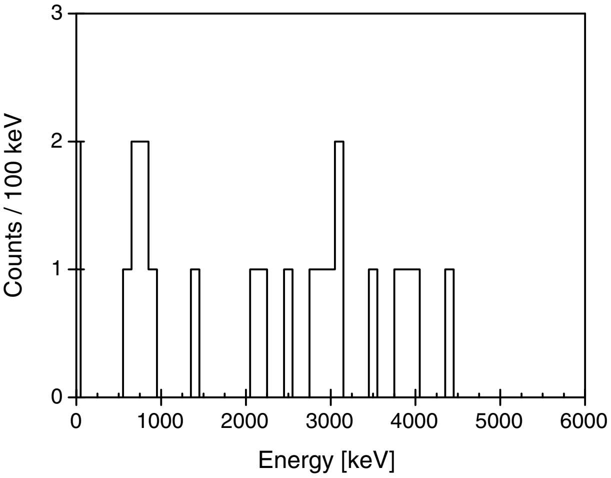

Fig. 2. Energy spectrum of βp events following the implantation of ^{50}Ni ions.

The βp energy spectrum of ^{50}Ni was obtained by requiring that a low-energy signal (see above and ref. [8]) was recorded within a time period of 100 ms following the implantation of a ^{50}Ni ion. Even though the statistics of the resulting βp energy spectrum, displayed in fig. 2, is rather poor, the events can be identified as being due to βp decay. The branching ratio for βp emission of ^{50}Ni was determined to be (70 ± 20)% by taking into account the estimated efficiency of (85 ± 10)% for βp detection as well as the experimental numbers of 23 βp events observed and 40 ^{50}Ni ions implanted. The probability to miss a ^{50}Ni βp event and record the βp decay of ^{49}Fe was estimated to be only ~ 3%. Therefore, this contribution was neglected. Due to low statistics and limited resolution, no further information can be gained on the structure of proton-emitting levels in ^{50}Co.

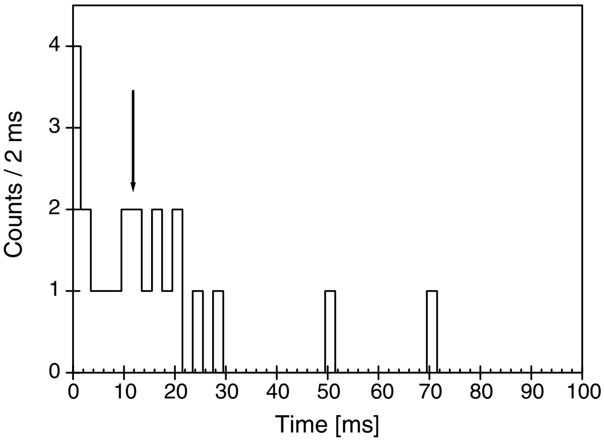

Fig. 3. Time distribution of βp events following the implantation of ^{50}Ni ions. The arrow indicates the half-life value found in this work.

The half-life of ^{50}Ni was estimated by evaluating the time differences between the implantation of ^{50}Ni ions and the subsequent βp events. The maximum waiting time for such decay events was fixed to 100 ms. A maximum of one ^{50}Ni ion implanted in any of the seven detectors per spill was registered. This rate is perfectly compatible with the correlation technique applied for half-lives in the 1 to 100 ms range. The time spectrum obtained in this way is displayed in fig. 3. The mean lifetime was obtained from these data by applying the maximum-likelihood method to an exponential distribution [16]. In this case, the best estimate of the mean lifetime is the arithmetic average. This method [17] can be applied since the lower limit for the measurable mean lifetime ($\sim 100\ \mu$s) is much smaller than its estimate, and the events were registered at such a low rate that a time window much larger than the lifetime could be employed. The lifetime value was found to be 17^{+5}_{-3} ms, corresponding to a half-life of 12^{+3}_{-2} ms, which agrees with the theoretical prediction of 16.8 ms [10] within two standard deviations.

In summary, we performed the first spectroscopic investigation of ^{50}Ni. Its βp decay was detected and the half-life measured to be 12^{+3}_{-2} ms. The branching ratio for βp emission of $(70 \pm 20)\%$ is compatible with the expected value of 100%. Further measurements with higher statistics, which may involve high-resolution γ-ray and higher-resolution βp detection, are necessary in order to study the structure of the daughter nucleus ^{50}Co.

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