First evidence for the two-proton decay of ^{45}Fe

M. Pfützner[1], E. Badura[2], C. Bingham[3], B. Blank[4], M. Chartier[5], H. Geissel[2], J. Giovinazzo[4], L.V. Grigorenko[2], R. Grzywacz[1], M. Hellström[2], Z. Janas[1], J. Kurcewicz[1], A.S. Lalleman[4], C. Mazzocchi[2], I. Mukha[2], G. Münzenberg[2], C. Plettner[2], E. Roeckl[2], K. Rykaczewski[1,6], K. Schmidt[7], R.S. Simon[2], M. Stanoiu[8] and J.-C. Thomas[4]

[1]Warsaw University, Poland; [2]GSI, Darmstadt, Germany; [3]University of Tennessee, Knoxville, USA; [4]CEN Bordeaux-Gradignan, France; [5]University of Liverpool, UK; [6]ORNL, Oak Ridge, USA; [7]University of Edinburgh, UK; [8]GANIL, Caen, France

In an experiment performed at the GSI Fragment Separator (FRS) in July 2001, the decay of ^{45}Fe has been investigated in order to establish whether it proceeds by simultaneous emission of two protons from the ground state, as suggested by theoretical predictions [1, 2], or by conventional β^+ decay. This extremely neutron-deficient nucleus was produced in the fragmentation of a 650 MeV/nucleon ^{58}Ni beam impinging on a 4 g/cm^2 Be target. The average beam intensity was about 4×10^8 ions/s. In order to reduce the number of contaminant ions transmitted through the FRS, an aluminum degrader was mounted at the first FRS focus in addition to the standard achromatic degrader at the middle focal plane. Ions reaching the final focus were identified in-flight using the $B\rho$-TOF-ΔE method. The time-of-flight (TOF) was determined by means of 3 scintillator detectors located at the second, third and final focal planes, respectively. The energy loss (ΔE) was measured with an ionization chamber.

After identification, the ions were slowed down in an aluminum degrader of variable thickness and implanted into a telescope of eight Si detectors, each 60 mm in diameter and 300 μm thick. The telescope was mounted inside a 30 cm long NaI(Tl) detector, composed of six crystals forming a barrel with inner and outer diameters of 8 cm and 40 cm, respectively. The NaI detector allowed to provide efficient discrimination against β^+ events which are accompanied by at least two annihilation photons. The probability to detect at least one γ photon following the β^+ decay of ^{49}Ni and ^{50}Co was measured to be 93 %.

Decay signals from the Si detectors were processed using specially developed preamplifiers with a fast-reset function, allowing to block the input circuit by an external logical pulse. In this way, low-energy decay signals (≈ 1 MeV) could be detected already a few microseconds after the implantation of a heavy ion which is accompanied by a release of up to 1 GeV in the same detector. A detailed description of the applied detection setup is given in Ref.[3].

During $\approx$140 hours, six ions of ^{45}Fe were implanted in the Si telescope. Five of these implantation events could be correlated with decay signals occurring later in the same detector, see Table 1. (Ion number 4 was implanted into a detector which decay spectroscopy setup was temporarily malfunctioning.) In one decay (event 3), the energy of about 10 MeV was released and a coincident photon was observed in the NaI detector. This event is consistent with the β-delayed proton emission scenario. In each of the other four decay events, a completely *different* pattern is observed: the energy of $\approx$1 MeV is released in the Si detector where the ion was stopped, with no other signal in coincidence. Such a pattern is expected if ^{45}Fe decays by the emission of two protons from the ground state.

A detailed analysis of possible sources of background radiation was undertaken. It was found that the probability to observe a random background-induced decay signal, with about 1 MeV and occurring within 10 ms after implantation of a heavy ion, was smaller than 10^{-3}. This leads us to conclude that the decay signals observed to be correlated with implanted ^{45}Fe ions do represent the decay of this nuclide.

The half-life estimated by a applying a maximum-likelihood method to the five data points is $T_{1/2} = 3.2^{+2.6}_{-1.0}$ ms. Our data suggest that ^{45}Fe decays predominantly ($\approx$ 80 %) by the emission of two protons with the total energy of 1.1 ± 0.1 MeV.

The measured decay energy is in very good agreement with estimated Q-values for 2p emission: (1.154 ± 0.094) MeV [1] and (1.279 ± 0.181) MeV [2]. The half-life is found to be in reasonable agreement with the prediction of a rigorous three-body model of 2p radioactivity, developed by Grigorenko et al. [4], which yields $T_{1/2} = 13$ ms for $Q = 1.1$ MeV.

A more detailed description of the data analysis and discussion of the results has been published in Ref.[5]. The results of another ^{45}Fe decay study, performed at GANIL, support our conclusions [6].

Table 1: Implantation detector, decay energy and decay time recorded for each of the six ^{45}Fe events observed (events are ordered chronologically).

Event	Detector	E [keV]	T [ms]
1	4	1000 ± 120	0.644
2	3	990 ± 130	5.276
3	5	10010 ± 100	3.395
4	5	-	-
5	2	1150 ± 100	1.196
6	2	1200 ± 100	12.617

References

[1] B.A. Brown, Phys. Rev. C **43**, R1513 (1991).
[2] E. Ormand, Phys. Rev. C **53**, 214 (1996).
[3] M. Pfützner *et al.*, Nucl. Instr. and Meth. A **493**, 155 (2002).
[4] L.V. Grigorenko *et al.*, Phys. Rev. C **64**, 054002 (2001).
[5] M. Pfützner *et al.*, Eur. Phys. J. A **53**, 279 (2002).
[6] J. Giovinazzo *et al.*, Phys. Rev. Lett. **89**, 102501 (2002).