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Short Note

Total absorption spectroscopy of ^{58}Cu decay

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Abstract. The β decay of ^{58}Cu has been studied by means of total absorption γ-ray spectroscopy. The β feeding to the ^{58}Ni states has been measured, and the strength of the ^{58}Cu(1^+) $\rightarrow$ ^{58}Ni(0^+) Gamow-Teller transition has been determined with improved accuracy.

PACS. 23.40.-s Beta decay; double beta decay; electron and muon capture – 27.40.+z $39 \leq A \leq 58$

1 Introduction

The most direct information on the Gamow-Teller (GT) transition strength (B(GT)) can be obtained from β-decay studies. Obviously, only transitions to states lying within the Q_β window can be investigated in such measurements. However, it is known that GT giant resonances, exhausting a large fraction of the B(GT) sum rule, appear at excitation energy of about 10–15 MeV, which is often in a region unreachable in β-decay studies. Therefore, to explore the B(GT) distribution beyond the β-decay window and in particular in the GT resonance region, charge-exchange (CE) reactions at intermediate energies have been used [1,2]. Since in the CE reactions a main part of the total GT strength can be measured, data obtained from these studies are particularly important for the discussion of the so-called "quenching" of the GT strength and related topics [3].

The determination of the GT transition strength from the CE reaction studies relies on the proportionality between the B(GT) and the reaction cross-section measured at 0° [4]. However, to find the absolute B(GT)-values calibration standards are needed. These standards are provided by the β-decay studies: In some cases the strength of the GT transitions extracted from CE reactions can be directly related to the B(GT) determined in the β-decay measurements. This concerns in particular the (p,n)-type CE reactions on even-even targets where the GT transition, connecting the 0^+ initial state with the β-decaying 1^+ state of the final odd-odd nucleus, involves the same GT matrix element as the reverse $1^+ \rightarrow 0^+$ GT β-decay. The strength of these GT transitions is used to normalize B(GT)-values obtained from CE reaction studies.

In this paper we present results of β-decay studies of ^{58}Cu by means of a Total Absorption Spectrometer (TAS) [5]. The main goal of the measurement was an accurate determination of the $1^+ \rightarrow 0^+$ ground state to ground-state branch in the β-decay of ^{58}Cu. The strength of this GT transition ($B(\mathrm{GT})_0$) is required to normalize B(GT)-values obtained in recent high-resolution studies of the ^{58}Ni(^{3}He, t)^{58}Cu reaction [6].

So far $B(\mathrm{GT})_0$ was established in only one experiment [7] in which the total number of ^{58}Cu decays was determined by detecting the annihilation radiation. The decay branch to the ground state of ^{58}Ni was deduced from the intensity balance in the ^{58}Cu decay scheme. This method requires an accurate determination of the intensities of individual γ lines. In particular summing effects and escape of energetic positrons from the radioactive sample have to be taken into account.

The TAS offers a simple way of detecting the positron decay to the ground state of the final nucleus. In an ideal

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total-absorption detector all γ-rays depopulating an excited state would be summed with two 511 keV annihilation quanta and yield an output signal corresponding to the excitation energy of the state plus 1022 keV. In the case of positron decay to the ground state, only two annihilation quanta are registered in the TAS.

In the following, details of the present TAS measurement of ^{58}Cu β-decay will be outlined and the results obtained will be presented. A preliminary account of this work has already been given in ref. [8].

2 Experimental method

^{58}Cu was produced in the reaction of a 5.5 MeV/u ^{40}Ca beam and a 2 mg/cm^2 thick $^{\mathrm{nat.}}$Si target. The reaction products were stopped and ionized in the FEBIAD-E ion source of the GSI on-line separator. The mass-separated $A = 58$ beam was implanted into a transport tape which periodically moved the accumulated activity to the center of the TAS. The collected sources exclusively contained ^{58}Cu activity as ^{58}Ni is stable and the ^{58}Zn ($T_{1/2} = 86$ ms) and ^{58}Co ($T_{1/2} = 71$ d) activities were negligible due to their low-production cross-sections and due to the choice of a transport time of 0.8 s and a measurement time of 8 s. In the TAS, the radioactive sources were positioned between two 600 μm thick silicon detectors used for recording positrons. To reduce the penetration of positrons into the TAS crystal, the detectors were surrounded by 2 cm thick polyethylene absorbers. By demanding coincidence between the TAS signal and the signal from the silicon detectors, the positron component of the β^+/EC decay was selected.

Figure 1 shows the positron-gated TAS spectrum collected at mass 58 during a measurement time of 3.5 hours. The spectrum is dominated by the peak at 1022 keV corresponding to the total absorption of two annihilation quanta following the positron decay of ^{58}Cu to the ground state of ^{58}Ni.

3 Data analysis and results

The quantitative determination of β-decay branching ratios from the TAS spectrum requires decomposition of the measured spectrum into contributions from the positron decays to individual ^{58}Ni states. In the analysis of the ^{58}Cu TAS spectrum we adopted the energies and the decay patterns of excited ^{58}Ni states known from high-resolution spectroscopy [7]. For all γ-rays assigned to the decay of ^{58}Cu the response of TAS was simulated by using the GEANT3 package [9]. The detector response for a cascade of γ transitions was constructed by folding the TAS spectra simulated for individual γ-rays. The quality of the simulation of electromagnetic cascades was verified by comparing the computer-generated detector response with the TAS spectra measured for ^{137}Cs, ^{60}Co and ^{24}Na calibration sources. Very good agreement between the measured and simulated spectra was achieved.

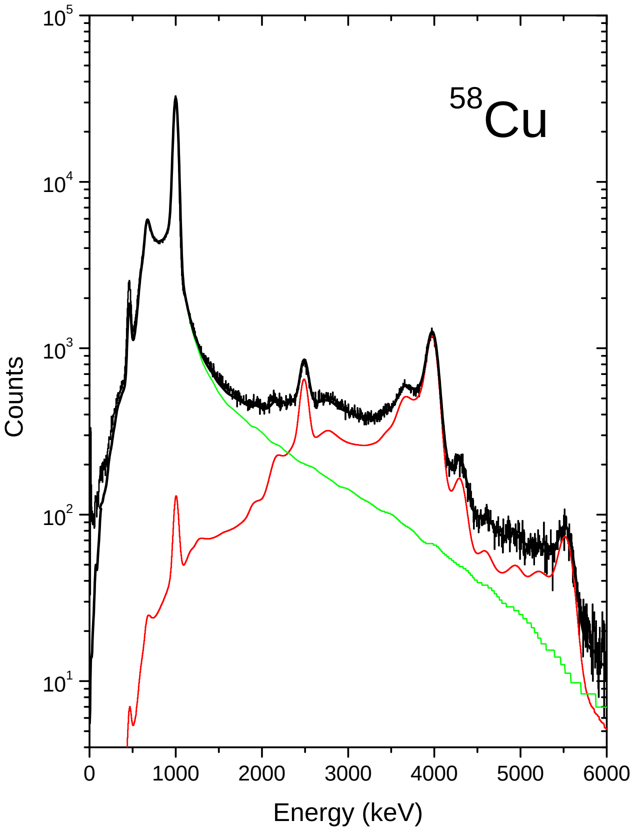

Fig. 1. Total absorption spectrum measured for the positron decay of ^{58}Cu decomposed into parts corresponding to the feeding of ground state and excited states in ^{58}Ni. The high-energy tail of the 1022 keV peak is due to positrons penetrating into the TAS crystal.

The TAS response for positrons was obtained by simulating their interaction with the different materials present in the TAS. The energy spectrum of positrons was sampled from the theoretical distribution with the maximum energy of the particles fixed by the ^{58}Cu Q_{EC}-value and the excitation energy of the level fed. The response of the TAS to a positron decay to an excited state was constructed by folding the detector response for positrons with the responses for all known cascades de-exciting the populated level. The contribution of the specific deexcitation path was weighted by the branching ratio obtained in the high-resolution measurements [7].

To determine the distribution of β^+ feeding as a function of ^{58}Ni excitation energy, the shape of the measured TAS spectrum was described as a superposition of the simulated TAS responses for the positron decays to the ground state and to known excited states of ^{58}Ni. The intensities of the positron transitions were treated as fit parameters in the χ^2 minimalization procedure. As illustrated in fig. 1, a very good description of the overall shape of the measured spectrum was obtained.

In the fitting range restricted to energies higher than 511 keV the χ^2-value converged to 1.6 per degree of freedom. A minor departure of the simulated spectrum from the experimental data for energies lower than 511 keV

Table 1. Branching ratios for the β^+/EC decay of ^{58}Cu to ^{58}Ni states.

E^a_{ex} (keV)	$I_{\mathrm{EC}+\beta^+}$ (%)	
	This work	Jongsma *et al.* [7]
0	81.2 ± 0.5	82 ± 3
1454.6 ± 0.2	1.37 ± 0.03	1.3 ± 0.9
2776.0 ± 0.5	0.47 ± 0.06	—
2902.8 ± 0.3	3.9 ± 0.3	4.3 ± 1.5
2943.2 ± 0.3	10.7 ± 0.4	9.7 ± 1.8
3038.7 ± 0.4	0.31 ± 0.06	0.31 ± 0.05
3264.6 ± 0.2	0.91 ± 0.03	1.10 ± 0.15
3532.2 ± 0.7	0.13 ± 0.06	0.069 ± 0.017
3594.9 ± 0.3	0.01 ± 0.05	—
3898.4 ± 0.8	0.11 ± 0.02	0.13 ± 0.03
4449.9 ± 0.4	0.84 ± 0.03	0.81 ± 0.13
4538.3 ± 0.6	0.14 ± 0.03	0.099 ± 0.021

[a] Excitation energies of ^{58}Ni levels from ref. [7].

is most probably due to the imperfect description of the positron penetration process. The total (EC + β^+) intensities of β-decay branches of ^{58}Cu were calculated by using the intensities of positron transitions obtained from the fit of the TAS spectrum and applying theoretical values of EC to positron decay ratios [10]. The total intensities of all β branches were summed up and normalized to 100%. The resulting absolute branching ratios are listed in table 1 for all ^{58}Ni states considered in the analysis of the TAS spectrum. For comparison, feedings of the ^{58}Ni states determined in the high-resolution studies [7, 11] are also given in the table. With the exception of the 2776 keV state, the branching ratios resulting from both measurements agree very well. In particular, our value of (81.2 ± 0.5)% feeding to the ^{58}Ni ground state in the decay of ^{58}Cu agrees well with the ground-state decay branch of (82 ± 3)% measured by Jongsma *et al.* [7,11] and is in excellent agreement with a value of (80.8 ± 0.7)% obtained in a very recent high-resolution experiment [12].

Our value of the ground-state branching ratio, the ^{58}Cu half-life of (3.204 ± 0.007) s [13] and the decay energy $Q_{\mathrm{EC}} = (8563 \pm 2)$ keV [14] yield a $\log(ft)$-value of 4.870 ± 0.003 for the $^{58}\mathrm{Cu}(1^+) \rightarrow {}^{58}\mathrm{Ni}(0^+)$ transition. We note that the statistical rate function f was calculated by using the tabulation of Wilkinson and Macefield [15] who included the radiative correction factor $(1 + \delta_{\mathrm{R}})$ in their definition of the f function. The $B(\mathrm{GT})$-value was obtained according to the relation:

$$B(\mathrm{GT}) = \frac{(6145 \pm 4)\,\mathrm{s}}{(g_{\mathrm{A}}/g_{\mathrm{V}})^2 ft}\,, \tag{1}$$

where $g_{\mathrm{A}}/g_{\mathrm{V}} = -1.266 \pm 0.004$. The corresponding $B(\mathrm{GT})_0$-value amounts to 0.0517 ± 0.0004.

4 Summary

The TAS measurement of the ^{58}Cu decay was performed to verify and improve the β feedings of the ^{58}Ni states known from the previous studies. The analysis of the TAS spectrum was based on the decay scheme established in the high-resolution measurements. We note, however, that only the energies and de-excitation patterns of ^{58}Ni states were adopted from the literature data. The β feedings of the individual ^{58}Ni levels were determined independently of the intensities determined in the high-resolution measurements. We obtained a very good description of the shape of the measured TAS spectrum, which yields β branching ratios very close to those found in the high-resolution studies. This confirms the essential features of the ^{58}Cu decay scheme proposed by Jongsma *et al.* [7], and allowed us to determine the probability of the ^{58}Cu ground state to the ^{58}Ni ground-state transition with improved accuracy. The $B(\mathrm{GT})$-value for this transitions was determined with an accuracy better than 1%. There is thus a firm basis available now for calibrating the $B(\mathrm{GT})$ distribution derived from CE reaction on ^{58}Ni, such as those obtained recently in a high-resolution $^{58}\mathrm{Ni}(^3\mathrm{He}, \mathrm{t})^{58}\mathrm{Cu}$ measurement in which $B(\mathrm{GT})$-values were determined for states with an excitation energy up to 14 MeV [16].

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