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Experimental Research of Emission of Positrons in Electron Capture of ^{54}Mn*

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Abstract: The internal electron-positron pair production accompanying the electron capture of ^{54}Mn was measured. The number of pairs was estimated by counting the annihilation photons. The obtained result is compared with our previous results and with the experimental result of other authors.

1. Introduction

The study of basic decays of nuclei showed that the nuclei can go to the lower energy states not only through the basic decay process, but there is some possibility of the transition through other accompanying processes. These processes are designated as the higher order processes. One from these processes is the process of the internal electron-positron pair production [1].

The higher order processes have essentially lower intensity then the basic decay processes. In the matter of the creation of electron-positron pairs accompanying alpha and beta decays the creation of one electron-positron pair belongs perhaps to 10^8–10^9 particles emitted in the basic decay process. The low relative probability of this process and the problems in the experimental research are the reasons that nowadays there is the lack of experimental data (for ^{54}Mn there is only one experimental result of other authors – only the upper limit for the branching ratio was estimated).

2. Experimental research

The expressive improvement of the quality of the detection technique, utilization of computers in experiments and better experimental conditions (detectors, low-level background shields, electronics, computers) make it possible to obtain the better precision experimental results for the experimental research of the internal electron-positron pair production at present. From this reason the experimental research of this process accompanying the basic decay processes of nuclei is very topical.

The main problem in the experimental research is that this low intensity process must be detected in the presence of the other higher intensity processes. For this reason for the successful experimental research of emission of the internal electron-positron pairs accompanying the basic decay processes the specific necessary conditions must be satisfied:

*) *Dedicated to Associated Professor Martin Chudý on the occasion of his 70th birthday.*

a) the high activity sources must be used,
b) the high radioactivity pure sources must be used,
c) the sources must not be the positron emitters,
d) the energy of the basic decay process is higher than $2m_{e}c^{2}$,
e) the background must be as low as possible,
f) the experimental equipment must have high sensitivity and high energy resolution,
g) because of long term measurements the high stability of the measuring equipment must be secured,
h) the decay scheme of nuclide must be simple.

Regarding to these specific conditions of the experimental research, we selected the best detection equipment appropriate for experimental study of electron-positron pair from the comparison of the value of the factors of merit.

The value of the factor of merit, *F*, is characteristic for low-level gamma-ray spectrometers. Spectrometer with the highest value *F* has the highest sensitivity (the lowest limit of detection) for detecting gamma-rays of energy *E* in presence of interference radiation coming from the natural background of the spectrometer and from gamma-quanta higher energy of the emitters present in the measured sample. In our measurements the measured sample did not obtain the impurity with high energy gamma-quanta and the types of detectors were similar, therefore the effect from the Compton continuum under the peak of energy *E* and the energy resolution can be neglected. For this reason the value of the factors of merit of spectrometers, *F*, were estimated from the equation

$$F \quad \frac{}{\sqrt{B_N}}\,, \tag{1}$$

where   is the peak efficiency for energy 511 keV and B_N is the natural background of the spectrometer in this energy region. We have a few NaI(Tl), Ge(Li) and HPGe detectors. We measured the factors of merit for various spectrometers in single and coincidence connections of these detectors in our Low-level Gamma-spectrometry Laboratory at the Department of Nuclear Physics and Biophysics. The highest value of the factor of merit, F = 45.25±0.88, was obtained for the coincidence HPGe-NaI(Tl) spectrometer. The used large-volume semiconductor coaxial HPGe detector has the sensitive volume 280 cm^3, the relative efficiency 69%, the ratio peak /Compton has the value 66.7 and the energy resolution for 1.33 MeV peak ^{60}Co is 2.12 keV. The scintillation NaI(Tl) detector has the crystal dimension   100 100 mm. Electronic modules NIM fy Silena were used.

It was evident from the obtained results that, for detection of coincidence gamma-quanta in the measurements of low-level gamma-ray spectrometry, it is the most advantageous to use the coincidence HPGe-NaI(Tl) spectrometer.

Since the probability of creation of one electron-positron pair has a very low relative probability, we designated the minimum measurable activities (MMA) for our coincidence HPGe-NaI(Tl) spectrometer from the measured background spectra (B) and peak efficiency ( ) under the chosen relative standard deviation ( ) and total time of the measurement (T = 30 days). The values of MMA were obtained according to the formula

$$\mathrm{MMA} \quad \frac{1 \quad 2 \quad \sqrt{BT}}{{}^{2}T}\,. \tag{2}$$

Values of MMA and the ratio MMA toward activity A of the source ^{54}Mn (MMA/A) are listed in Table 1.

Table 1. The minimum measurable activity and the ratio of MMA/A.

	MMA [Bq]	MMA/A
0.1	(3.39±0.07) 10^{2}	(3.46±0.04) 10^{7}
0.5	(5.75±0.12) 10^{3}	(5.88±0.11) 10^{8}

It is seen from Table 1 that our coincidence HPGe-NaI(Tl) spectrometer is able to measure the number of electron-positron pairs already at relative intensity 10^{8}. Similar results were obtained in our work [2].

The number of electron-positron pairs was estimated by counting the annihilation photons with the coincidence HPGe-NaI(Tl) spectrometer. This spectrometer, besides the highest value of the factor of merit, connects the quality of the good energy resolution of the semiconductor HPGe detector with the high sensitivity of the registration of the scintillation NaI(Tl) detector. The single HPGe spectrometer was used for the estimation of the radioactivity impurity in the measured sample. The ^{54}Mn is very suitable nuclide for the experimental research of the internal electron-positron pairs because its decay scheme is very simple and the energy of the basic decay is sufficient for creation of electron-positron pairs. The decay scheme of ^{54}Mn according to [3] is shown in Fig. 1. The activity of ^{54}Mn was (97.8±1.5) kBq.

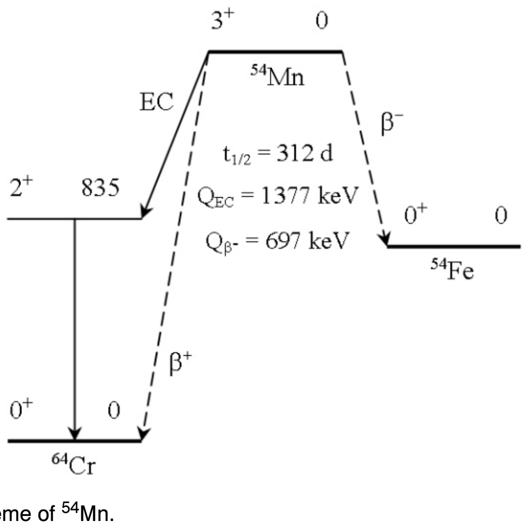

Fig. 1. The decay scheme of ^{54}Mn.

The detectors were located in the good-quality low-level background shield characteristics of which were described in the work [4].

The measured spectra were evaluated with the program EMCAPLUS made by fy Silena. The measured coincidence spectra of the background and ^{54}Mn (the number of

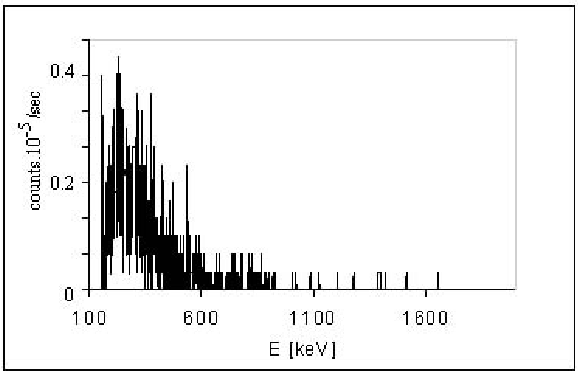

Fig. 2. Coincidence spectrum of the background.

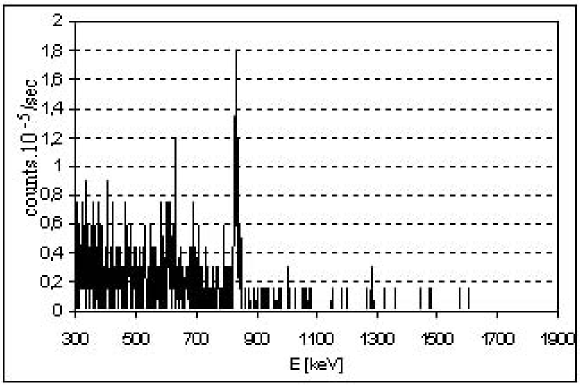

Fig. 3. Coincidence spectrum of ^{54}Mn.

impulses registered per second in dependency on the energy) are shown in Fig. 2 and Fig. 3. Time of the measurements of both spectra was more than 10^6 seconds.

3. Results

The results of our measurements were corrected for the possible sources of annihilation radiation, which may contribute to the measured number of positrons. The special care was taken to estimate the contribution of these sources of the annihilation radiation:

1. A correction for the annihilation peak in the background.
2. A correction for the external pair production by high-energy photon originating in the sources.
3. A correction for the possibility of some radioactive impurities, which decay by positron emission (^{65}Zn, ^{22}Na).

4. A correction for the contribution of nuclei produced by (, n) reactions and subsequently decayed by positron emission.
5. A correction for the production of neutrons accompanying spontaneous fission.
6. A correction for the impurities present in the sources which emit cascade quanta with the energy (511±2) keV and other with higher energy.
7. A correction for the annihilation of positrons in the flight.
8. A correction for the random coincidence rate.

The correction for the annihilation peak in the background was the most important. Other corrections were small and totally did not exceed 25% of the measured values of the annihilation gamma-quanta.

Our experimental results of measurement of the internal electron-positron pair production accompanying electron capture of ^{54}Mn, previous and present, are compared with the result of other authors in Table 2.

The correction for the presence of some radioactive impurities, which decay by positron emission (^{65}Zn, ^{22}Na), was made by measurements sample of ^{54}Mn by the single HPGe spectrometer. It was evident from the measured data that source ^{54}Mn does not contain the positron sources ^{65}Zn and ^{22}Na, but it contains the nuclide ^{60}Co. Other radioactive impurities were not found. Data evaluation gave the result that the activity of ^{60}Co presented in our source was (3.82 Bq. Our present experimental result the ratio of the probability of the production of the electron-positron pair to the probability of the basic decay process of ^{54}Mn was presented at the conference [7].

Table 2. Comparison of our results the ratio of the probability of the production of the electron-positron pair to the probability of the basic decay process of ^{54}Mn, with the results of other authors.

Source	$T_{e^- e^+} / T_{EC}$			
	Our results		**Results of the other authors**	
	previous	present	experimental	theoretical
^{54}Mn	< 7 8 [5] (6.3±5.6) 8 [6]	(4.7±3.4) 8	< 4.4 8 [3]	don´t exist

4. Conclusion

The measurement of the emission of electron-positron pairs accompanying the radioactive decay the electron capture of ^{54}Mn showed that number of measured positrons is at grade as the value of the minimum measurable activities of our coincidence spectrometer and for this reason it is probably necessary to measure this effect for a longer time. The use of the stronger source is problematical with respect to the summation effect of characteristic gamma ray of ^{54}Mn. Our obtained result of the emission of internal electron-positron pairs emitted from ^{54}Mn is in good harmony with our previous results and with the result of B. Sur et al., but our present result is more accurate.

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