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Internal Electron-Positron Pair Production in Electron Capture of ^{54}Mn

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Abstract: The measurement of the internal electron-positron pair production accompanying the electron capture of ^{54}Mn has been made. This higher-order effect is much less intense than the basic decay process. One electron-positron pair belongs to the 10^8 of the basic decay process. The number of electron-positron pairs was estimated by counting the annihilation photons. In the measurements single HPGe and coincidence HPGe-NaI(Tl) spectrometers were used. The detectors were located in the low-level background shield. The obtained result is compared with our previous result and with the experimental and the theoretical results of other authors.

1. Introduction

The theoretical and experimental research of electromagnetic and weak interactions in atom nuclei are interested in the electromagnetic effects, which modify and change the basic decay processes of nuclei. These effects are the cause that the nuclei, which are in the excited states, can go to the lower energy states not only through the basic decay process but there is some possibility of the transition through the other accompanying processes. These processes are designated as the higher order processes [1].

The typical higher order processes accompanying decays of the nuclei:

i) internal bremsstrahlung,
ii) ionization and excitation of the electron cloud,
iii) internal electron-positron pair production.

These higher order processes have essentially lower intensity then the basic decay processes. One photon of the internal bremsstrahlung belongs to the 10^2–10^5 emitted particles. The internal ionization is ~10^4 times smaller than the probability of the basic decay process of the nucleus. The relative probability of the internal electron-positron pair production is the smallest. One electron-positron pair belongs to the 10^8–10^9 particles emitted in the basic decay process.

The low relative probability of the higher order processes and the problems in the experimental research are the reasons that there are still some open problems where the experimental results are not in harmony and the theory is not able to explain correctly these processes. Expressive improvement of the quality of the detection technique, utilization of computers in experiments and better experimental conditions (low-level background shield, electronics, computers) make it nowadays possible to obtain the better precision look for these processes. From these reasons the experimental research of the higher order processes is necessary.

2. Internal Electron-Positron Pair Production

Process of internal electron-positron pair production (IPP) accompanying the basic decay processes may occur in two modes [1]:

1. charged particles, originated in a nuclear decay (alpha, beta), are accelerated in the Coulomb field of the daughter nucleus and emit bremsstrahlung with energy above $2m_ec^2$, these produce the electron-positron pairs,
2. the daughter nucleus originated in an excited state and the resulting gamma-quantum (real or virtual) is converted to the electron-positron pair.

Both processes are possible, however, according to the theory, the probability of the first process is a few orders higher than the probability of the second process and for this reason the first process has the dominant contribution to the IPP.

3. Experimental Procedure

In the experimental research of the internal e^+e^- – pairs production accompanying electron capture (EC) of ^{54}Mn, it is necessary to use the high sensitivity detection equipment. The main problem is that this low-level intensity process must be detected in the presence of the other processes which have higher intensities.

We used HPGe and NaI(Tl) detectors in the measurements of the IPP. The detectors were located in the good-quality low-level background shield characteristics of which were described in work [2]. In the single connection we used the semiconductor HPGe-spectrometer with the high factor of merit. We used this spectrometer for the estimating of the radioactive impurities in the measured samples of ^{54}Mn. The number of electron-positron pairs was estimated by counting annihilation photons with the coincidence HPGe-NaI(Tl) spectrometer. This spectrometer connects the quality of the good energy resolution of the semiconductors HPGe spectrometer with the high sensitivity of the registration of the scintillation NaI(Tl) detector. The used large-volume semiconductor coaxial HPGe detector has sensitive volume 280 cm^3, relative efficiency 69 %, ratio peak/Compton has value 66.7 and energy resolution for 1.33 MeV peak ^{60}Co is 2.12 keV. The scintillation NaI(Tl) detector has the crystal dimension of 100 100 mm. Electronic modules NIM by fy Silena and 4096 channels amplitude analyzer ICA-70 were used. The measured spectra were evaluated with the program EMCAPLUS made by fy Silena.

4. Results

The internal e^+e^-–pairs have been observed in the electron capture of ^{54}Mn. In Table 1 our obtained results are presented. In the previous measurement of the IPP accompanying EC of ^{54}Mn we were able to determine only the limit for the ratio of the probability of the production of the internal e^+e^-–pair to the probability of the basic decay process [3].

Table 1. The ratio of the probability of the production of the internal electron-positron pair to the probability of the basic decay process for electron capture of ^{54}Mn.

Source	$T_{e\ e+}/T_{EC}$		
	Our results	Results of other authors	
		Experimental	Theoretical
^{54}Mn	previous		
	$< 7.10^{-8}$		
		$< 4,4.10^{-8}$ [4]	…
	present		
	$(6,3 \pm 5,6).10^{-8}$		

The biggest experimental problem was, that the annihilation peak is located on the "Compton region" of the 834.8 keV gamma rays. This region is created by random coincidences of Compton scattered gamma-rays with 511 keV annihilation radiation and must be subtracted. The results of our measurements were corrected for the possible sources of annihilation radiation which may contribute to the measured number of positrons. We described the sources of annihilation radiation in article [3]. High-energy photons originating from cosmic rays and the background radioactivity from surrounding materials can interact via pair production in the region between the two counters. The resulting radiation from positron annihilation is an important source of background and special care was taken to estimate the contribution of this. The correction for the annihilation peak in the background was the most important. The contribution from the annihilation peak of the background in the measured values was about 90 %. Other corrections were small and totally did not exceed a few per cents of the measured values of the annihilation gamma-quanta. We published a more detailed calculations and description of the experimental equipment used in the measurements of IPP in article [5].

5. Conclusion

The new experimental result of the measurement of the IPP accompanying EC of ^{54}Mn which we obtained is in a good agreement with our previous result. This result is also in good agreement with the experimental result of other authors. Other experimental and theoretical results of other authors up to now do not exist. Our previous result of the measurement of the IPP accompanying the EC of ^{54}Mn together with the results of measurements IPP in alpha decay of ^{210}Po, ^{239}Pu and ^{241}Am and in beta-decay of ^{32}P were published and presented at conferences [6–8].

The low relative probability of the IPP accompanying the basic decay processes, the problems in the experimental research and failure of number of experimental results make it impossible to develop the theory of this process. A more detailed calculations and further experimental results would be of considerable interest.

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