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Internal Bremsstrahlung Accompanying Orbital Electron Capture of ^{54}Mn

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Abstract: The internal bremsstrahlung (IB) accompanying the electron capture of ^{54}Mn was measured. From the measurement of the end-point energy of IB spectrum the decay-energy of this nucleus was determined. The obtained result is compared with the experimental result of the other authors and with the theoretical result.

1. Introduction

Nowadays the theoretical and the experimental research of the electromagnetic and weak interactions in atom nuclei are interested in the electromagnetic effects, which modify and change the basic decay processes of nuclei. In the theory of the weak interactions, these effects are attributed to the terms of the higher orders. These effects are the cause of the fact 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.

2. Internal Bremsstrahlung

The internal bremsstrahlung is a typical higher order process accompanying the basic decay processes. There is some probability in the decay processes of nuclei in the emission of beta particle also in the capture of orbital electron that these basic processes are accompanying by simultaneous emission of electromagnetic radiation. The origin of this secondary radiation is due to the interaction of the current carrier with the Coulomb field of the daughter nucleus. This radiation is generally designated as the internal bremsstrahlung accompanying beta decay IB(β) or electron capture IB(EC) contrary the external bremsstrahlung (EB) that is originated in the interaction current carrier with the Coulomb field outside the daughter nucleus [2]. In the case of IB(β) the presence of EB has the dominant effect for the accuracy of the experimental result because the form of the energetic spectrum of EB is similar to spectrum of IB. Generally, the intensity of EB is one-two order higher than the intensity of IB. The probability of the emission of the photon IB is very low. One photon IB belongs to the 10^2–10^5 of the basic decay processes. From this reason the experimental research of IB was concentrated only on relatively few nuclides decay diagrams of which are the simplest. For both processes, for IB(β) and for IB(EC), the theories were made based on the same principle of the independent processes: the emission of beta particle or electron capture and the creation the photon of IB. Even though that these theories regard a lot of corrections (the effect of Coulomb field of daughter nucleus, momentum, bonding energy, shielding influence of the electrons and others), the differences between theories and experiments still remain. The inaccuracy of the experimental results is often up to 50 % and, therefore, they do not enable to develop the contemporary theoretical models of these processes.

The low relative probability of this higher order process and the problems in the experimental research are the reasons that there are still some open problems where the experiment and the theory are not in harmony. It is caused mainly by the lack of experimental data. 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 possible to obtain the better precision look for these processes at present. For this reason the experimental research of the internal bremsstrahlung accompanying the basic decay processes of nuclei is very topical.

3. Experimental Research of the Internal Bremsstrahlung

The main problem in the experimental research of IB is that this low intensity process must be detected in the presence of other higher intensity processes. For this reason, in the experimental research of IB the nuclides must be used decay scheme of which is very simple, the activity of the sample must be high and it is necessary to use the high sensitivity experimental equipment. With regard to these specific conditions of the experimental research, we studied the characteristics of some detection systems suitable for the high sensitivity measurements. We used high volume scintillation and semiconductor detectors in different connections. We found from the comparison of the size of the factors of meritthat in the experimental research of IB, it is necessary to use the single HPGe spectrometer or the coincidence HPGe-NaI(Tl) spectrometer in relation to the decay scheme of the measured nuclides. The coincidence spectrometer connects the quality of the good energy resolution of the semiconductor HPGe-spectrometer with the high sensitivity of the registration of the scintillation NaI(Tl) detector.

The detectors were located in a good-quality low-level background shield characteristics of which were described in works [3, 4]. 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. The measured spectra were evaluated with the program EMCAPLUS made by fy Silena.

4. Results

Internal bremsstrashlung accompanying electron capture IB(EC) of ^{54}Mn was measured. Nuclide ^{54}Mn is very suitable for experimental research of IB because of its simple decay scheme. Simple scheme makes it possible to use the coincidence between photons IB and characteristic gamma radiation. During the measurement the activity of ^{54}Mn was (98.6 ± 1.5) kBq. The radioactive impurity of ^{54}Mn was measured by single HPGe-spectrometer. In Fig. 1. single spectra of ^{54}Mn and the background are shown.

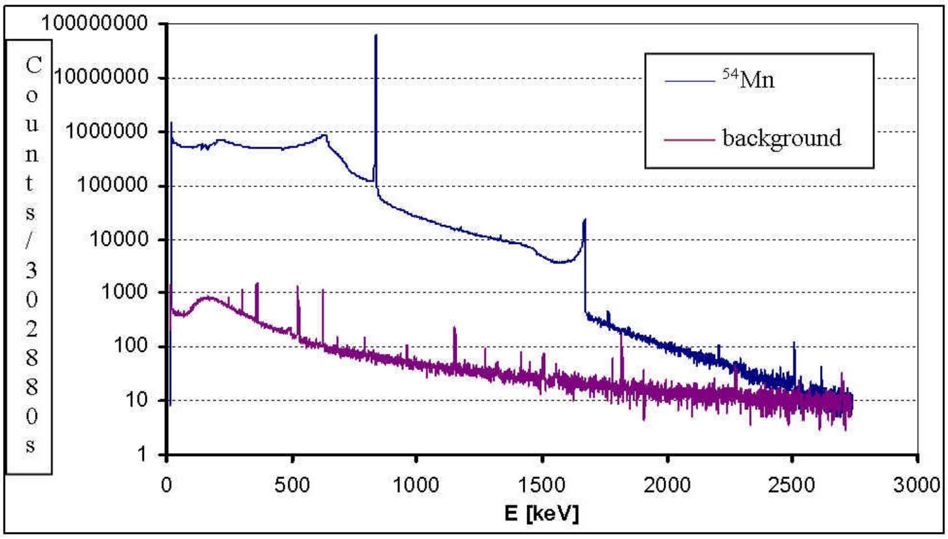

Fig. 1. Single spectra of ^{54}Mn and the background.

After the correction for background we obtained the radioactive impurity of ^{54}Mn. In Table 1 gamma–peaks are shown which were determined from the measured spectra. The star in Table 1 marks the low intensity peaks (error is more than 15 %). The most of them were not identifiabled. Peaks marked P belong to the background (^{214}Bi and ^{208}Tl). In the measurements peaks created summation of gamma rays of energy 834.85 keV of ^{54}Mn (marked sum) were registered. It is evident from the measured data that source ^{54}Mn contains ^{60}Co. Data evaluation gave result that the activity of ^{60}Co presented in our source was equal to (3.82 0.10) Bq.

IB(EC) ^{54}Mn and the random coincidence rate were measured by the coincidence HPGe-NaI(Tl) spectrometer. A simplified block diagram of this spectrometer is shown in Fig. 2.

Is shown spectrum IB(EC) ^{54}Mn obtained by subtraction of standardized spectrum of random coincidence from the spectrum of serious coincidence in Fig. 3 . The correction by subtraction the appropriate Compton distribution was made for residual counting rate in the region of peak 834.8 keV.

Table 1. Observed gamma-peaks measured in the nuclear decay ^{54}Mn by single HPGe-spectrometer.

Peak number	**Legend**	**Energy** [keV]	**Counting rate** [s ^{1}]	**Error** [%]
1	* P	511	0.02017	37.97
2	*	749.89	0.0175	32.83
3	^{54}Mn	834.85	658.33	0.01
4	^{60}Co	1173.2	0.03467	4.21
5	^{60}Co	1332.5	0.02967	4.02
6	2x sum	1669.7	0.30833	0.49
7	*	1729.02	0.00053	35.19
8	P	1764.5	0.00317	8.02
9	P	2204.2	0.00067	14.7
10	*	2422.82	0.00013	33.04
11	* P	2447.8	0.00025	26.59
12	3x sum	2504.5	0.00147	6.11
13	P	2614.5	0.00054	12.9

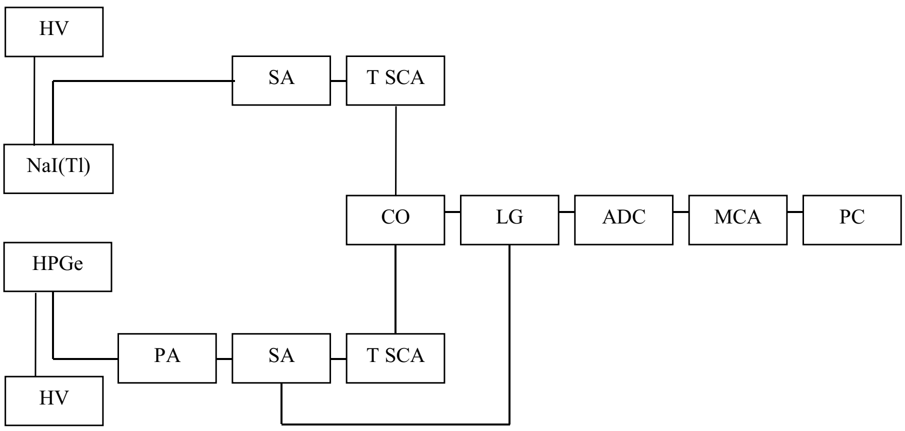

Fig. 2. A simplified block diagram of the coincidence HPGe-NaI(Tl) spectrometer (HPGe and NaI(Tl) – detectors, HV – High voltage, PA - Preamplifier, SA – Spectroscopy amplifier, T SCA – Timing single channel analyzer, CO – Coincidence unit, LG – Linear gate, ADC – Analogue-to-digital converter, MCA – Multichannel pulse-height analyzer, PC – Personal computer).

Our experimental result of the measurement of the IB accompanying electron capture was corrected for the possible sources which could distort the number of the measured photons of IB. The measured coincidence spectrum of the source ^{54}Mn was corrected for:

1 the background,
2 the detection efficiency,
3 the Compton distribution,

4 the contribution of EB,
5 the absorption photons IB in absorber,
6 the absorption photons IB in the source,
7 the summing effect,
8 X-radiation,
9 the random coincidence rate,
10 the dead time.

The method of least squares was used for estimation of the end-point of the spectrum IB. Through the energy of the end-point of the IB spectrum and using the magnitude of the binding energies according [5] was established for the sources ^{54}Mn the transition energy through EC decay. Comparison of the transition energy through electron capture decay E_{EC} for ^{54}Mn is listed in Table. 2. In this Table our experimental result is compared with the experimental results of other authors and with the theoretical value.

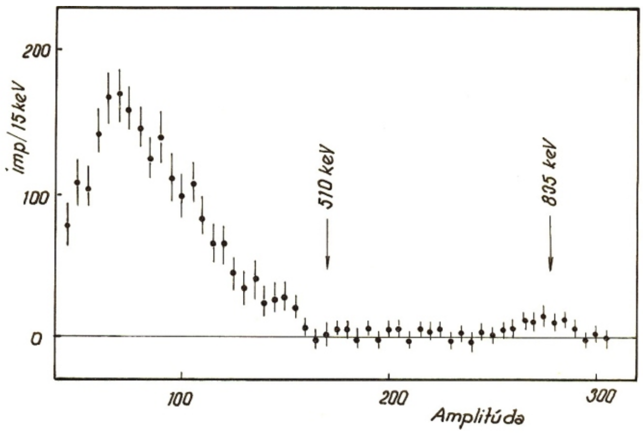

Fig. 3. Coincidence spectrum of ^{54}Mn corrected for the random coincidence rate.

Table 2. The transition energy E_{EC} for ^{54}Mn.

Nuclide	E_{EC} (keV)		Authors
	Theory	Experiment	
^{54}Mn	540.1 3.6	516 15	Our result
		518 8	[6]
		639 ± 100	[7]

It is seen from the Table 1 that our experimental result is in harmony with the experimental results of the other authors however the difference between these experimental results and the theoretical value obtained according to [8] shows that the received mass difference of the mother and the daughter atomic nucleus ^{54}Mn - ^{54}Cr is not correct.

5. Conclusion

Our result of the transition energy E_{EC} for ^{54}Mn obtained from the measurement of the energy of the end-point IB spectrum of ^{54}Mn is in good harmony with the results of the other authors, but there still exists the discrepancy of these results with the theoretical one. For elimination of this discrepancy and for a better understanding of the process of IB it is necessary to continue in the experimental research. Precision results can help in the future to develop up-to-date theories. In the future we would like to use the matrix of the spectral sensitivity for data evaluation of the IB measured spectrum. In that case the experimental results ought to be more accurate. Such results create the possibility to find the systematic differences between the theory and the experiment. It is possible to use the coincidence spectrometer IB–X-ray in the experimental research of IB accompanying electron capture of nuclei.

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