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EXPERIMENTAL ARRANGEMENT FOR INVESTIGATION OF β^+-DECAY END-POINT ENERGIES

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Dedicated to Professor Kseno Ilakovac on the occasion of his 70$^{\text{th}}$ birthday

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We describe an experimental arrangement for the investigation of β^+-decay end-point energies based on the use of a surface barrier silicon detector for β-particles and two Ge(HP) detectors for photons in a three-axes detection geometry. The system was tested using a ^{58}Co source. The positron end-point energy determined by the Fermi plot analysis of the experimental data was found to be in good agreement with the values quoted in the literature.

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1. Introduction

Precise measurements of β-decay end-point energies are important for the determination of nuclear decay schemes and for better understanding of β-decay processes. Energy distribution of β-particles emitted in decay processes are given by the well known bell-shape curves. At the end-point energy, signal-to-background ratio becomes very small. In order to improve this ratio, it is useful to use the coincidence technique, if possible. In the case of β^+-decays, coincidences between two 511 keV annihilation γ-rays and β^+-particles are a natural choice. In this work, we describe an experimental arrangement for the investigation of β^+-decay end-point energies using a surface barrier silicon detector for positrons and two Ge(HP) detectors for photons, operating in coincidence mode and placed in a three-axes geometry.

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2. Source preparation and calibration

To minimize the energy losses of β^+-particles, all components of the source holder were made of light materials. The source holder is shown schematically in Fig. 1.

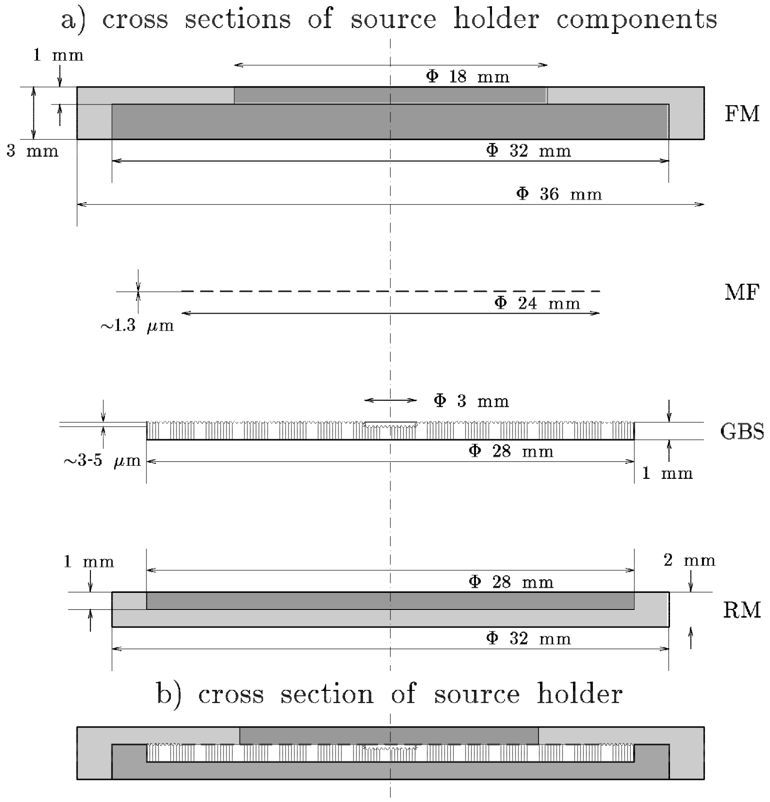

Fig. 1. Schematic view of the source holder. FM, MF, GBS and RM denote front mount, Mylar foil, glass backing with shallow pit (for radionuclide sample) and rear mount, respectively.

Main test of the experimental arrangement was performed using a ^{58}Co β^+-emitter source. Decay scheme of ^{58}Co radionuclide is shown in Fig. 2. The ^{58}Co radionuclide substance was prepared by nuclear reaction ^{59}Co(n,2n)^{58}Co at the Hungarian Nuclear Institute in Budapest. Accompanying reactions ^{58}Co(n,2n)^{57}Co and ^{59}Co(n,γ)^{60}Co yielded impurity radionuclides ^{57}Co and ^{60}Co, respectively. The 1 mCi of ^{58}Co radionuclide preparation was dissolved in 0.1 M HCl and sampled in a glass vial. The source was prepared by the deposition of a drop of the ^{58}Co radionuclide solution into a shallow pit at the centre of a glass disc. After drying, a thin layer of the radionuclide formed a spot of 3 mm in diameter and average thickness of 2.3 μm. To avoid radionuclide evaporation, the source was covered with 1.3 μm thin Mylar foil. For the source activities A and the number of atoms N in the source, we found $A(^{57}\mathrm{Co})/\ A(^{58}\mathrm{Co}) = 1/333$, i.e., $N(^{57}\mathrm{Co})/N(^{58}\mathrm{Co}) \simeq 1/100$, and $A(^{60}\mathrm{Co})/A(^{60}\mathrm{Co}) = 1/2777$, i.e., $N(^{60}\mathrm{Co})/N(^{58}\mathrm{Co}) \simeq 1/100$. Therefore, the contribution of ^{57}Co and ^{60}Co impurities to the total number of ^{58}Co nuclei was negligible.

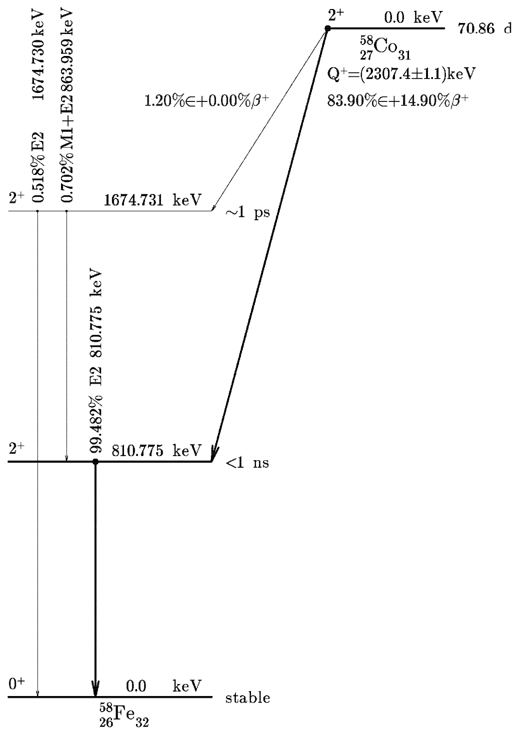

Fig. 2. The decay scheme of ^{58}Co *based on data from Refs. [1, 2]. We are interested in the positron decay from ground state of* ^{58}Co *to the first excited state of* ^{58}Fe*, which is followed by pure E2 γ-decay.*

For the calibration purposes, radioactive ^{137}Cs and ^{207}Bi were prepared using a similar techniques as the one used for the preparation of ^{58}Co. In addition, a set of IAEA γ-sources was used for γ-calibrations.

In the region between 300 keV and 600 keV, the output channel numbers were found to be proportional to the corresponding β-particle energies. The energy calibration factor (3.802 keV/channel) was determined from the measured spectra of β-particles of known energies: ^{133}Cs (624.218 keV), ^{58}Co (803.7 keV) and ^{207}Bi (481.65 keV, 554.42 keV and 975.6 keV). Furthermore, the output number of counts under peaks were found to be proportional to the corresponding β-particle intensities. Therefore, measured β-energy distributions were negligibly distorted.

3. Detectors

For β-detection, an EG&G Ortec silicon charged-particle detector, having a nominal active area 50 mm^2, a sensitive thickness of 1.5 mm, and front Au and rear Al electrodes of thickness 40.0 μg/cm^2. The reverse current 0.56 μA at +300 V was used. For γ-detection, two similar Canberra Ge(HP) coaxial detectors (one open end and one closed end facing the window), each of a diameter of 47 mm, length 36.5 mm, active area 17.3 cm^2, facing window at the distance of 5 mm, depletion voltage +4000 V and relative efficiency 13%, were used.

4. Geometry

The source and the detectors spanned a three-axes detection geometry, each axis originating from the source. Source and the positron detector, facing each other, were coaxially mounted inside an Al cylindrical chamber with the outer diameter of 7.0 cm, length of 12.5 cm and thickness of 1 mm. The source-to-detector distance was (5.9 ± 0.1) mm.

Generally, to maximize the coincidence counting rate, the γ-detectors should be mounted along the directions obeyed by β-γ correlation of the decay. In the particular case, there is no β-γ angular correlation, and the γ-detectors are to be faced at the distance of 7.0 cm and coaxially mounted perpendicularly to the source – β-detector axis. So, a compact T-geometry has been chosen.

In the measurements with the ^{58}Co source [1,2], two Ge(HP) detectors were detecting 511 keV annihilation radiation and were placed at 180° with respect to the source. The ground state of ^{58}Co decays mainly by positron emission to the first excited 2^+ state in ^{58}Fe at 810.8 keV. This state decays with the half-life of less then 1 ns by the emission of the 810.8 keV γ-ray. Therefore, the emitted γ-ray is coincident with positrons and the two annihilation radiations.

Because β^+ decay of the ^{58}Co ground state to the first excited state of ^{58}Fe is $\Delta J^{\Delta\pi} = 0^+$, it is an allowed transition and the accompanying β- and γ-radiations are not space-correlated [3]. This means that positrons emitted in the ^{58}Co decay and the 810.8 keV γ-rays emitted from the first excited state of ^{58}Fe are coincident but not directionally correlated [4]. Therefore, ^{58}Co is a very convenient source for testing the experimental arrangement of the compact T-geometry.

5. The system detection properties and data acquisition

During the measurements, the chamber with the sources and the β-detector was at atmospheric air pressure and room temperature. The energy loss of 624.218 keV conversion electrons in the ^{137}Cs source caused an energy shift of -2.0 keV. In addition, since the conversion electrons passed through air from the ^{137}Cs source to the β-detector, energy shift of -2.0 keV per 1 cm path in air was found which matched with the relevant data in literature [5]. The energy losses of β-particles from the ^{58}Co source and the ^{207}Bi sources were found to be the same as those for the ^{137}Cs source. The overall energy resolution of the β-detector in the region between 300 and 600 keV was about 9 keV. However, if the β-detector was cooled down to liquid nitrogen temperature, it's resolution was improved to about 3 keV. The energy resolutions of the γ-detectors were about 1.5 keV.

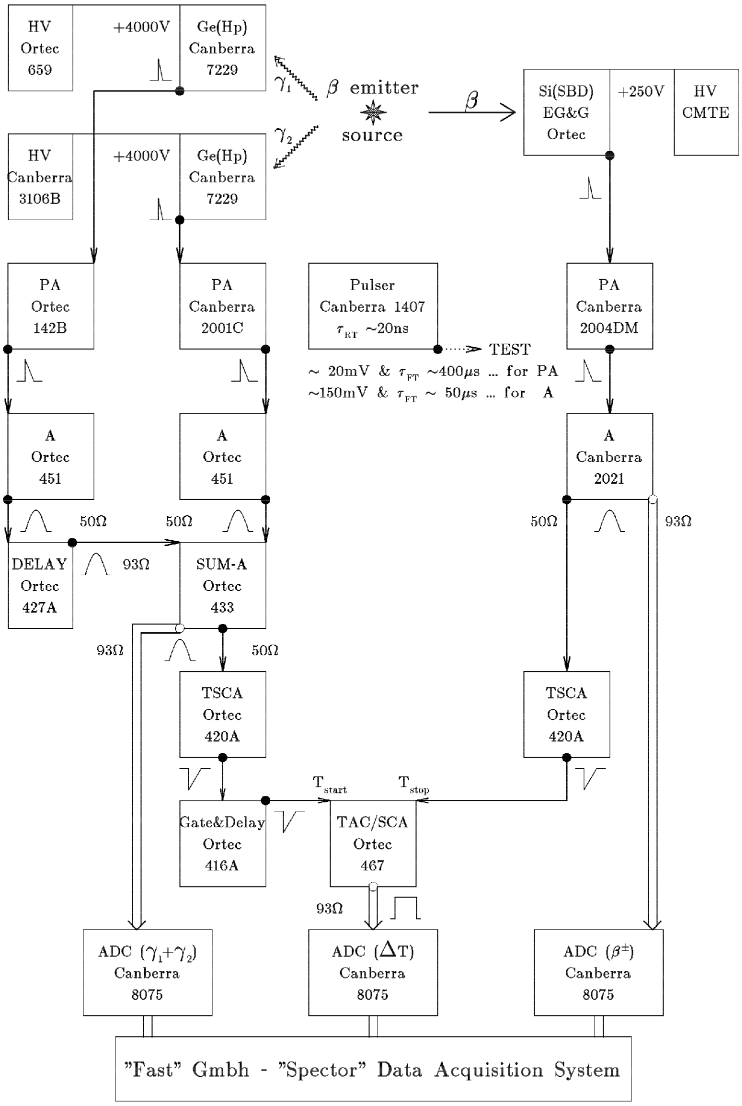

Fig. 3. Block scheme of detecting, processing, and data acquisition electronics for the three-axes detecting geometry. HV, PA, A, SUM-A, TSCA, TAC/SCA and ADC denote high-voltage power supply, preamplifier, amplifier, sum amplifier, timing single-channel analyser, time-to-amplitude and analog-to-digital converter, respectively. The Spector system was running in the singles mode for calibration purposes and in coincidence mode for testing the experimental arrangement.

Standard NIM units were used for the processing of pulses from the three, and a FAST GmbH Spector data-recording system was used for the accumulation of data (see Fig. 3). For the set up and calibration purposes, the Spector system was run in the independent mode (singles-spectra). Then it was adjusted for the coincidence mode. Finally, the system was run in the coincidence mode and two dimensional β-γ events from the ^{58}Co decay were recorded.

Because (i) the ADC-ranges were set to 256 channels and (ii) the overall energy resolution of the β-detector in the region between 300 and 600 keV was about 3 channels, the measured β-energy distributions were negligibly distorted and were appropriate for the fitting procedure in that region.

6. *Analyses and results*

The two-dimensional records from the ^{58}Co coincident β-γ decay events were collected and analysed. First, a minimally dissipative β^+-particle spectrum in co-

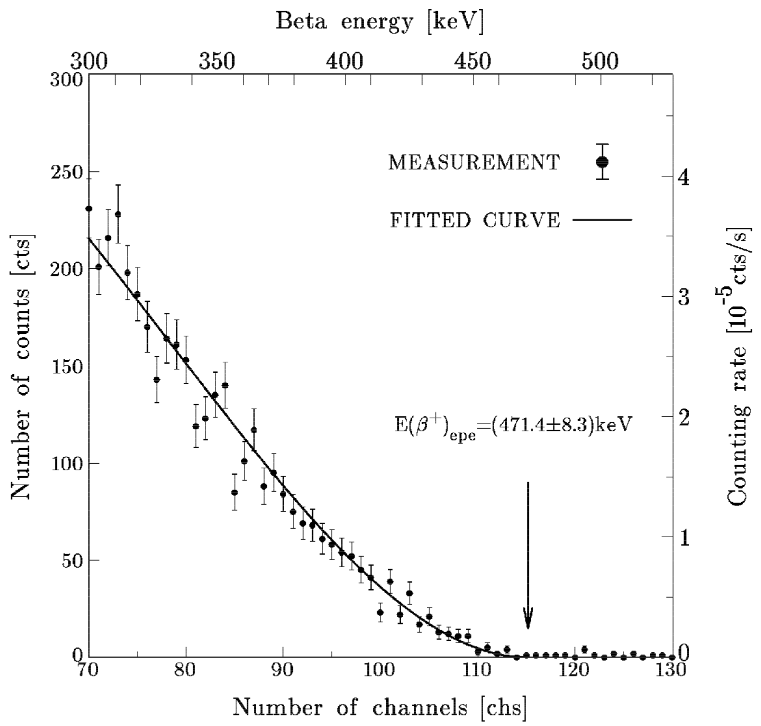

Fig. 4. Net spectrum of positrons from ^{58}Co β^+*-decay feeding the first excited level of* ^{58}Fe. *Fitting the theoretical energy distribution [6] to this positron spectrum, the end-point energy was found to be* (471.4 ± 8.3) keV *with the reduced chi-square* $\chi^2 = 0.8$.

incidence with the sum of 810.764 keV γ-rays and the narrow double annihilation γ-peak was extracted. Then, a net β^+-particle spectrum was derived by subtracting the background events. The spectrum is shown in Fig. 4.

A Fermi plot with the experimental β^+-particle spectrum, fitted by the theoretical β^+-particle energy distribution [6] resulted in a linear plot which intersects the energy axis at the β^+ end-point energy of $E_{\rm EPE} = (471.4 \pm 8.3)$ keV. This value is in good agreement with value of (474 ± 5) keV published in Ref. [7]. The error was mainly determined by the β^+-detector energy resolution and it could be improved in the way quoted in the previous section.

7. Conclusion

The described experimental arrangement is based on (i) a β-detector and two low-energy γ-detectors arranged in a three-axes geometry, (ii) a three-parameter system for the single and coincident data acquisition and (iii) the application of modern computational analyses. The arrangement is specially designed for the investigation of β^+-decay end-point energies although its modifications for wider use in β-γ spectroscopy is also possible. It was successfully tested using a ^{58}Co radioactive source.

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MJERNI SUSTAV ZA ISTRAŽIVANJE KRAJNJE ENERGIJE U β^+-RASPADU

Opisujemo mjerni sustav za istraživanje krajnje enegije u β^+-raspadu zasnovan na upotrebi površinskog silicijskog detektora za β^+-čestice i dvaju Ge detektora visoke čistoće za fotone, u trokrakom razmještaju. Sustav smo ispitali pomoću izvora ^{58}Co. Krajnju energiju pozitrona odredili smo analizom mjernih podataka primjenom Fermijevog dijagrama, i ustanovili dobro slaganje s ranije objavljenim vrijednostima.