I. 5. Isospin Mixing in the Superallowed Fermi Transition −The Decay of ^{54}Co−

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Isospin mixing affects the transition rates of T = 1, $0^+ \rightarrow 0^+$ superallowed β-decays and thus plays an important role in the precise determination of the vector coupling constant of weak interaction, G_V, which is directly related to the V_{ud} quark-mixing element of the Kobayashi-Masukawa matrix describing the three-generation Standard Model.

A major source of uncertainty in the extraction of the value of G_V from nuclear beta decay is the size of the necessary charge-dependent corrections. These corrections, which arise from the imperfect overlap of the parent and daughter-state wave functions, alter the transition rates of superallowed $0^+ \rightarrow 0^+$ β-decays by about one percent. It is difficult to verify the accuracy of corrections since there is no case that is free of charge-dependent effects.

One way of directly testing the calculations is to look for those small, missing parts of the wave functions that have been mixed from the lowest 0^+ states into excited 0^+ states. Any non-analog β-decay branches to excited 0^+ states into daughter nucleus can only proceed through such admixtures and thus offer a direct test of the predictive powers of the calculations. The measurement of the strength of such branches is very difficult, however, since even the strongest branch is expected to be in the 10^{-5} range. They have only been observed in one case of ^{42}Sc. Thus more systematic studies are requested for the non-analog $0^+ \rightarrow 0^+$ transitions on the nuclei having superallowed Fermi decays.

We briefly report the experimental status of the measurements of weak non-analog $0^+ \rightarrow 0^+$ transition in the decay of ^{54}Co, which have been done by different and complementary methods; one is using the purely mass-separated source by IGISOL (Sendai), the other using the intense sources efficiently transferred by a He-jet system (Chalk River).

It has been reported that the T = 1, 0^+ ground state of ^{54}Co decays into the T = 1, 0^+ ground state of ^{54}Fe with 100% branching. No report has shown the β^+-transition to the 2561 keV 0^+ state of ^{54}Fe (non-analog state).

If the 2561 keV state were populated it should decay by feeding the 1408 keV, 2^+ first excited state in ^{54}Fe with a 1153 keV γ-ray. Since the 2nd and 3rd forbidden beta transitions to higher excited states in ^{54}Fe have even weaker strengths than the non-analog transition, the detection of the 1153 keV γ–ray proves the existence of the $0^+ \rightarrow 0^+$, non-analog transition which can only take place through isospin mixing.

The strength of the samples must be kept quite high, with peak decay rates close to 10^6 s^{-1}, because the branch searched for is extremely weak. Furthermore, the another obstacle to measure the weak transition is the existence of troublesome Compton-scattered background by intense gamma transitions from the β^+-decay of ^{54}Co 7^+ isomer. This requires the careful preparation of samples by proper energy selection of the incident beam if ^{54}Co is produced by ^{54}Fe(p,n) reactions, and very pure target materials.

Experiment at Sendai:

The fast on-line mass-separation system IGISOL was used to prepare the pure samples of ^{54}Co. The $\beta - \gamma$ coincidence measurement was done with an HPGe detector and two plastic scintillators on either side of the sample on the tape. Several runs with various incident beam energies were tested to tune the optimum beam energy offering the best S/N value near the 1153 keV region in the γ-ray spectrum. Since the present maximum yield of mass-separated ^{54}Co was about 10^4 atoms for 4 μA, the total number of ^{54}Co decays observed has been limited to 2 x 10^8 decays. Although the γ-ray spectrum has small contamination from the isomer decay and no contamination from other activities, it did not show the signal of 1153 keV. The development to obtain a better efficiency of IGISOL system is in progress.

Experiment at Chalk River:

Large amounts of ^{54}Co were produced in a helium-filled target chamber containing 15 thin ^{54}Fe targets and efficiently transported with a NaCl-loaded He-jet system with a 12.5m long capillary. Intense samples of ^{54}Co were deposited onto a transport tape and periodically moved to the γ- and β-detector positions. The γ-rays were observed with a 70 % HPGe detector shielded by a 15 mm thick aluminum absorber and a 15 mm thick lead shielding to avoid the direct exposure to the numerous positrons (10^6 dps). The HPGe detector is operated together with two thin plastic scintillators for positron detection. HPGe events are accepted if they are coincident with a signal from one of the scintillatros and not coincident with the other one. The setup is almost the same as that at Sendai. The total number of ^{54}Co decays is determined, after the γ-ray measurement, with a continuos-flow gas counter that has an efficiency of 92 % for high energy positrons.

A total number of 9.5 x 10^9 decays of ^{54}Co were studied and we have made the first observation of the 1153 keV γ-ray which follows the beta transition to the 2561 keV non-analog 0^+ state. The preliminary result of the branching ratio to this state is 4.5 x 10^{-5}. The predicted value of this branching ratio by Hardy and Towner [1] is 2 x 10^{-5}.

The continuous efforts are progressing on other superallowed transitions such as ^{50}Mn, ^{46}V and so on.

Reference

1) Hardy J. C., Towner I. W., Koslowsky V. T., Hagberg E. and Schmeing H., Nucl. Phys **A509**(1990).