Inner bremsstrahlung accompanying beta decay in ^{90}Sr-^{90}Y

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The inner bremsstrahlung spectrum accompanying first forbidden beta decay in ^{90}Sr-^{90}Y has been measured in the energy region from 80 to 600 keV with a 4.5×5.1 cm NaI(Tl) scintillation spectrometer. The magnetic deflection technique was employed in conjunction with a good geometry setup. After making all the corrections, viz., background, energy resolution, Compton electron distribution, detection efficiency (including geometry factor), and can absorption, the measured pulse height distribution is compared with (1) the allowed theory of Knipp and Uhlenbeck and Bloch, (2) the Coulomb-corrected theory of Lewis and Ford, and (3) the detour theory of Ford and Martin summing the contributions from ^{90}Sr and ^{90}Y in the investigated energy region. The measured pulse height distribution was found not to show agreement with any one of the theories. However, limited proximity exists between the measurements and different theories at different energy ranges.

[RADIOACTIVITY β decay, ^{90}Sr-^{90}Y, measured IB, magnetic deflection, NaI(Tl).]

I. INTRODUCTION

Inner bremsstrahlung (IB) is a weak continuous energy electromagnetic radiation that accompanies β decay. The basic theory of IB in β decay was developed for allowed transitions by Knipp and Uhlenbeck[1] and independently by Bloch.[2] This is called KUB theory and was extended to forbidden transitions with Coulomb correction by many authors: Chang and Folkoff,[3] Madansky *et al.*,[4] Nilsson,[5] Lewis and Ford[6] (LF), Felsner,[7] Janouch and Havranek,[8] Struzynski and Pollock,[9] Gebhardt,[10] and Ford and Martin.[11] Ford and Martin considered the contribution to IB from detour transitions in the forbidden decay process and worked out the theory for unique first forbidden transitions only. According to this theory the parent nucleus emits a photon and goes to a virtual intermediate state from which it subsequently β decays to the final state of the daughter nucleus or vice versa.

The literature survey in the field of IB reveals[12,13] that there is a lack of agreement between theory and experiment in the case of IB from most of the isotopes with forbidden decay character. The experimental results of IB in a few cases[14–24] indicate an excess over theory, the excess being higher the greater the photon energy. Attempts were made to account for the observed IB excess in terms of the "nuclear radiations" or "detour transitions," especially in the case of IB accompanying forbidden β decay. The present study was undertaken to investigate IB from ^{90}Sr-^{90}Y, which possesses a unique first forbidden character.

The decay scheme[25] of ^{90}Sr-^{90}Y is shown in Fig. 1. ^{90}Sr decays to ^{90}Y by emitting a β particle with an end-point energy of 546 keV. It has a half-life of 28.6 yr and a logft value of 9.4. Its decay is classified as unique first forbidden. ^{90}Y β decays (99.99%) to ^{90}Zr with an end-point energy of 2279.2 keV. Its half-life is 64.1 h and its logft value is 9.2. Its decay is also classified as unique first forbidden. A small fraction (0.01%) decays to a metastable

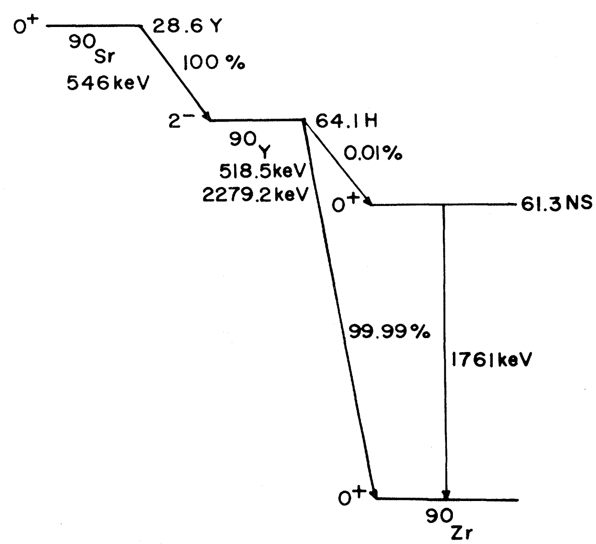

FIG. 1. Decay scheme of ^{90}Sr-^{90}Y.

state of ^{90}Zr at 1761 keV with a mean life of 61.3 nsec. ^{90}Zr decays from a metastable level to its ground state mostly by internal conversion.

^{90}Sr and ^{90}Y are in secular equilibrium. Bienlein *et al.*[26] investigated IB accompanying β decay in ^{90}Sr and ^{90}Y by separating the two isotopes from a ^{90}Sr-^{90}Y source with an ion exchange column. They used NaI(Tl) crystal and a β absorber between the crystal and source. The results were compared in both cases separately with KUB, LF, and Felsner theories. The results of ^{90}Sr showed an excess over all the theories. In the case of ^{90}Y the results showed agreement with KUB in the lower energy region. Singh and Al-Dargazelli[27] studied IB spectra from ^{90}Sr-^{90}Y in the energy region from 200 to 2200 keV. They compared the experimental results with the KUB, Lewis and Ford, and Nilsson theories in the lower energy region, summing the theoretical contributions from ^{90}Sr and ^{90}Y, and with the Felsner and Ford and Martin theories in the higher energy region where only the contribution due to ^{90}Y is present. In both the cases the results show a drastic deviation from all the theories. However, the evaluation of the theoretical contribution by these authors has been criticized.[28] Further, the authors placed the source inside a stainless steel chamber which allows for backscattering and production of external bremsstrahlung. Aluminum was placed as a β stopper in which not only external bremsstrahlung (EB) is produced but IB is also absorbed. Corrections must be made for all of these. When a magnetic field[29,30] is employed to deflect the β particles, these two errors are completely eliminated. Therefore it was thought worthwhile to reinvestigate IB accompanying β decay in ^{90}Sr-^{90}Y employing the magnetic deflection technique and adopting a better method of source preparation to minimize source scattering and EB production in the source holder.

II. EXPERIMENTAL DETAILS

A carrier-free liquid source of ^{90}Sr-^{90}Y with 1 mCi activity was obtained from the Isotope Division, Bhabha Atomic Research Centre, Bombay, India. The source for the experiment was prepared by evaporating the solution, drop by drop, on a thin Mylar film (1.7 mg cm^{-2}) cemented to a Perspex ring of 4 cm diameter and 2 mm wall thickness. Uniform spread of the source limited to a circular area of a diameter of 5–6 mm was achieved by adding a drop or two of dilute insulin to the source sample. The experimental arrangement used in the present work and the procedure adopted are described elsewhere.[31]

The IB spectrum was recorded with a 4.5×5.1 cm NaI(Tl) crystal mounted on an RCA 8053 photomultiplier which was coupled to a 512 channel multichannel analyzer. Calibration of the spectrometer was done using the following monoenergetic γ ray lines: ^{170}Tm (84 keV), ^{57}Co (122 keV), ^{141}Ce (145 keV), ^{203}Hg (279 keV), ^{51}Cr (320 keV), ^{113}Sn (392 keV), ^{22}Na (511 and 1274 keV), ^{137}Cs (662 keV), ^{54}Mn (835 keV), and ^{60}Co (1173 and 1332 keV). The source was placed at a distance of 32 cm from the face of the detector. The geometry was chosen such that the crystal was well shielded from EB produced by the source β particles in the pole pieces of the magnet. The IB spectrum was recorded for over 20 h. The stability of the counting system was maintained by checking it before and after the experiment with a 662 keV γ ray line. Since IB is of very low intensity, the background was recorded for the same time before and after each measurement. From the data accumulated over several runs, the average of six consistent readings was considered for the final evaluation of the spectrum. Though the spectrum was recorded for the entire energy range, the data for the final analysis were restricted to the region below 600 keV.

IB spectra of sources having strengths of 25, 35, and 42 μCi were recorded. The shapes of the background corrected IB spectra in all these did not change, showing that the contributions due to EB and pileup are negligible. The strength of the source used for the final measurement was 35±2 μCi.

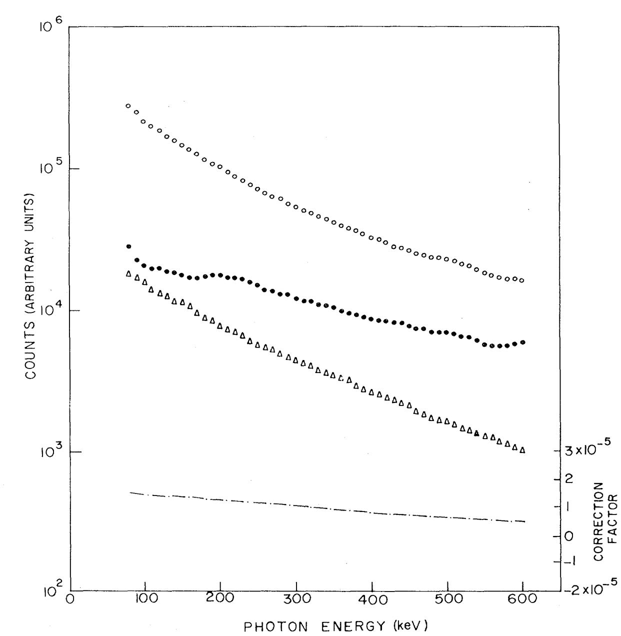

FIG. 2. Experimental pulse height distribution (○ ○ ○), background (●●●), Compton electron distribution (△ △ △), and correction factor for detection efficiency (—·—).

III. DATA ANALYSIS

The signal consists of the incident spectrum "folded" with the detector response function. Therefore, to retrieve the true spectrum the raw spectrum should be unfolded. In the current investigation we followed the method of Liden and Starfelt.[32] The details of the analysis are similar to those followed in an earlier IB work.[33] The background and resolution corrected data were corrected for Compton electron distribution from the end-point energy of 2279.2 keV of ^{90}Y down to 80 keV, K x-ray escape, γ-detection efficiency, including geometry and the absorption in the can. The experimental pulse height distribution along with the background, Compton electron distribution, and correction factor for detection efficiency, are shown in Fig. 2.

Errors. The errors involved in the present measurement are as follows: The statistical error due to counting is less than 0.5% below 250 keV, and it is about 1% near 500 keV. The errors involved in the corrections for resolution and Compton electron distribution are found to be less than 2% and 1%, respectively. The error in the determination of detection efficiency of the crystal is found to be negligible up to 200 keV, and it is about 0.50% around 300 keV, 1.30% around 400 keV, and 2% around 500 keV. Error due to correction for can absorption is found to be 0.7% at 80 keV, 0.4% at 300 keV, and negligible beyond this. The error in the determination of source strength, which is about 5%, is the most significant of all the errors. The overall rms error varies from 5.3% near 100 keV to 5.9% around 500 keV.

IV. RESULTS AND DISCUSSION

^{90}Sr-^{90}Y β particles have two different end-point energies. The theoretical computation of IB was carried out separately for the two sources and the corresponding numbers were added to evaluate the total spectrum. A similar procedure was followed by Gundu Rao *et al.*[33] in the case of IB from ^{170}Tm. In the present measurement the unfolded spectrum, represented as number of photons per MeV per β particle, is compared with the theoretical distributions of KUB (allowed), Lewis and Ford (forbidden), and Ford and Martin (detour), summed for contributions from ^{90}Sr and ^{90}Y (Fig. 3).

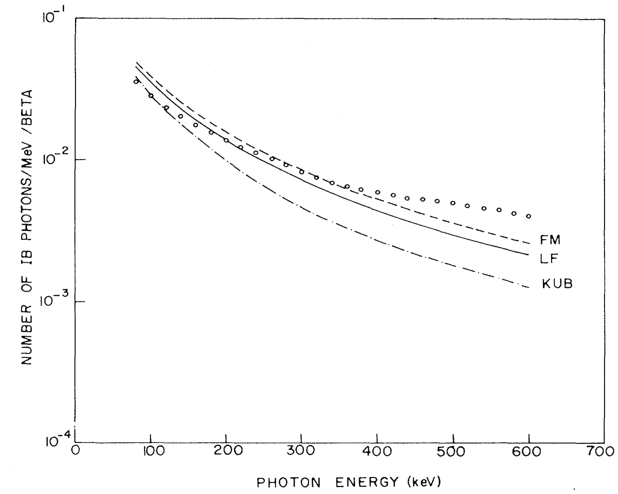

FIG. 3. Theoretical spectra KUB (—·—), LF (—), and FM (- - -) summed for ^{90}Sr and ^{90}Y along with unfolded experimental spectrum (○ ○ ○).

The results show that the experimental pulse height distribution does not match the calculations of any of the three theories, though they are close to KUB around 100 keV, close to LF around 200 keV, and close to FM over a considerable range up to 400 keV. Beyond this, the results show an excess over all the three theories. This trend is similar to the results of an earlier measurement,[26] which showed positive deviation from KUB and LF theories throughout the measured range of energies. The observed excess over theories, similar to the IB results from different forbidden β decay isotopes,[20,21,26] is hard to understand from the known characteristics of the IB phenomena.

ACKNOWLEDGMENTS

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