Indian J. Phys. **64A** (1), 63-69 (1990)

Radiative capture of orbital electrons in the decay of ^{57}Co

B R S Babu* and A Augusthy
Department of Physics, University of Calicut, Calicut University,
P. O.-673 635, India
and
P Venkataramaiah and H Sanjeeviah
Department of Physics, University of Mysore, Mysore-570 006, India

Received 21 April 1989, accepted 8 September 1989

Abstract : Inner Bremsstrahlung accompanying the Electron Capture (EC) decay of ^{57}Co to the excited state of 136.47 keV in ^{57}Fe was measured with a (4.5×5.1 cm^2) NaI(Tl) scintillation spectrometer. The measured pulse height distribution was corrected for the detector response following the procedure of Liden and Starfelt. The transition energy was determined to be 710.0±5.0 keV.

Keywords : EC-decay, measured IB, deduced transition energy.

PACS Nos : 25.40 Lw.

1. Introduction

When a nucleus decays by capturing one of the orbital electrons, the process is accompanied by simultaneous emission of electromagnetic radiation known as Inner Bremsstrahlung (IB). Moller (1937) and Morrison and Schiff (1940) independently developed the theory of IB in allowed transitions neglecting the Coulomb field effect of the nucleus. The IB spectral distribution thus obtained, follows the form $k(k_0-k)^2$ where k is the energy of the emitted photon and k_0 is the end point. When the measurements were extended to include photons at low energies, however, an unexpected steep rise in the intensity was noticed (Peterson 1965). Glauber and Martin (1956) and Martin and Glauber (1958) carried out extensive calculations for allowed capture from both K and L shells taking into consideration, the Coulomb field, relativistic and screening effects.

A relatively simple procedure for calculating the IB intensities for arbitrary k and Z was reported by Intemann (1971). The entire field of IB accompanying the EC decay was reviewed by Bambynek *et al* (1977).

---

*Present address : Saha Institute of Nuclear Physics, 92, Acharya Prafulla Chandra Road, Calcutta-700 009, India.

The agreement between the theory and experiment is not wholly satisfactory. The shapes of total spectra and partial *IS*-spectra have been measured for a number of allowed capture transitions, and found to be in good agreement with theory (Petterson 1965). However, the intensities of these spectra obtained mainly from IB-γ-coincidence studies show wide divergence from theoretical predictions (Bambynek *et al* 1977).

EC decay of ^{57}Co provides an example of an allowed transition ($\Delta J=1$, $\Delta\pi=0$, log ft.$=6.4$). Since the Z-value ($Z=27$) is not too low, Coulomb and other effects are expected to play fairly important role in the observed photon intensities following EC decay in this isotope. The transition energy was earlier measured by Jung and Pool (1956) and Lancman and Labowitz (1971) using IB-γ-coincidence technique. Jung and Pool reported a value of 434 ± 30 keV while Lancman and Labowitz reported a value of 674 ± 30 keV. There is a large discrepancy between these two measurements and both have large errors. Also these results differ significantly from that (700 ± 0.7 keV) reported in the mass tables (Wapstra and Bos 1977) and Wapstra and Audi (1985). Considering these, it was felt desirable to re-investigate the IB from this isotope for estimating the transition energy and look for possible Coulomb and relativistic effects on the IB intensities.

2. Experimental details

A 100 μCi carrier free ^{57}Co obtained from B. A. R. C., Bombay was used in the present investigation. The actual experimental source was prepared by evaporating the liquid drop by drop on thin mylar film mounted on a perspex ring of diameter 2.4 cm. Sufficient care was taken to have uniform spread by adding a few drops of dilute insulin. The IB pulse height distribution was detected using a 4.5×5.1 cm^2 NaI(Tl) detector. The pulses from the detector after suitable amplification are recorded in a MCA (EG and G ORTEC make). The spectrometer was calibrated using 122 keV (^{57}Co), 279 keV (^{203}Hg), 511 keV (^{22}Na), 662 keV (^{137}Cs), 835 keV (^{54}Mn), 1115 keV (^{65}Zn) gamma ray lines. The details of the experimental arrangement is similar to the one used in one of our earlier measurements excepting that now the magnetic field is removed (Babu *et al* 1985). The data was accumulated for several runs of 10 h. each and a total of 10 such consistent runs was considered for final analysis. The background was also recorded for the same time. The raw spectrum together with the corresponding background and Compton electron distribution is shown in Figure 1.

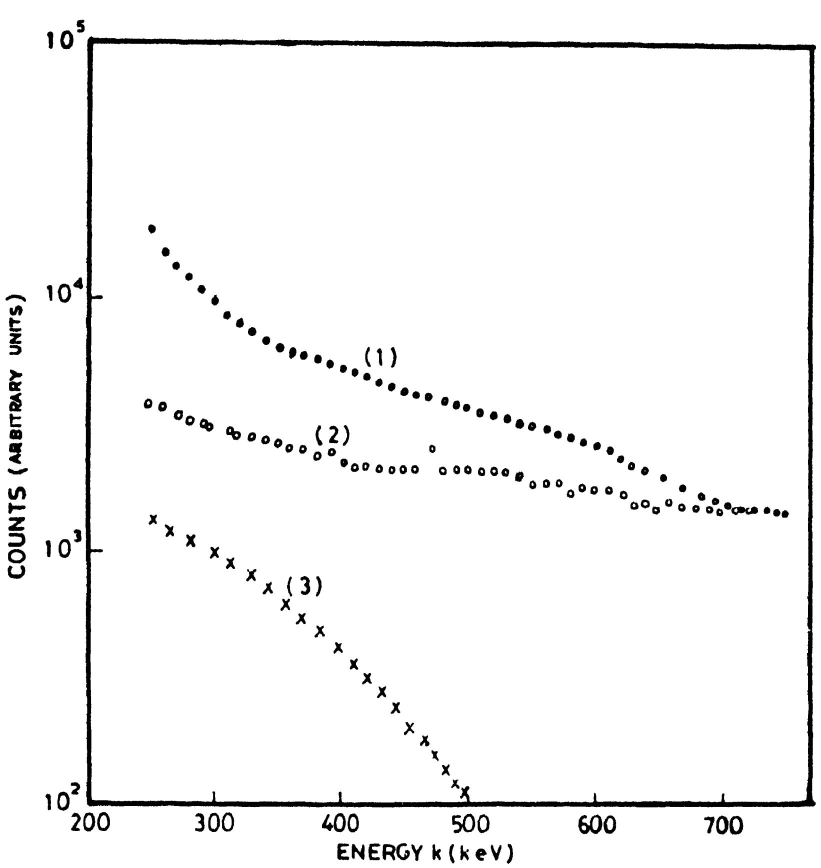

Figure 1. Raw experimental spectral : (1) Experimental distribution, (2) Corresponding background and (3) Compton electron distribution

3. Evaluation of IB spectra

The measured counting rate $N_{OB}(E_\gamma)$ in each channel is the sum of counts from Inner Bremsstrahlung $N_{IB}(E_\gamma)$, pile up $N_P(E_\gamma)$ and background $N_B(E_\gamma)$.

$$N_{OB}(E_\gamma)=N_{IB}(E_\gamma)+N_P(E_\gamma)+N_B(E_\gamma) \tag{3.1}$$

Contributions to the pile up come predominantly from the 122 keV gamma line. Therefore, restricting to first order summing, we may write

$$N_P(E_\gamma)=2\tau\int^{P} N(E-X).N(X)dX \tag{3.2}$$

where 2τ is the resolving time of the detecting system and $N E-X)$ and $N(X)$ are the number of photons with energy $(E-X)$ and X respectively. The integration is performed numerically to obtain $N_P(E)$ at each channel. Since the source strength used is very low, the pile up effects are found to be negligible. Also we have considered the experimental distribution beyond 250 keV for final analysis and the pile up effects are negligible beyond this region.

In order to obtain the true IB photon spectrum, the background subtracted IB spectrum should be corrected for the detector response. This was done following the procedure of Liden and Starfelt (1953) and the procedure is given elsewhere (Babu *et al* 1985).

4. Errors

The corrections to the measured IB pulse height distribution are due only to finite energy resolution, Compton electron distribution, detection efficiency and pile up. The correction due to finite energy resolution and pile up are found to be negligible. The correction due to detection efficiency contributes the final error and this is found to be 3-5% in the region 400-700 keV. The total r.m.s. error in the estimation of IB intensity is about 6%. The error on the end-point energy is obtained by least square fit analysis of the data.

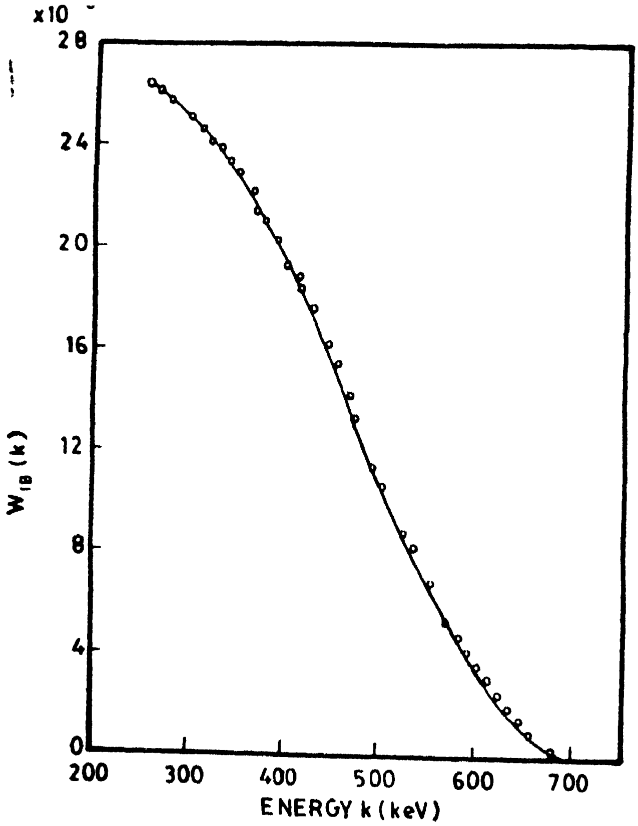

Figure 2. Comparison with theory: Solid line-Theoretical distribution and 00000 Experimental distribution.

5. Transition energy

The 1S–IB intensity distribution may be written as

$$\frac{dW_{1S}}{W_k}=\frac{\alpha}{\pi}\cdot\frac{k(q_{1S}-k)^2}{q_{1S}^2}\cdot R_{1S}.dk. \tag{5.1}$$

The above equation is used to deduce the end-point energy of 1S–IB spectrum by constructing the Jauch plot (Jauch 1951) to the measured IB spectrum according to

$$[W_{IB}^{\mathrm{EXP}}/kR_{1S}(Z,k)]^{1/2}=\left(\frac{\alpha}{\pi}\right)^{1/2}\left(1-\frac{k}{q_{1S}}\right)$$

Figure 3 is the resulting Jauch plot which yields an end point energy of 710.0 keV.

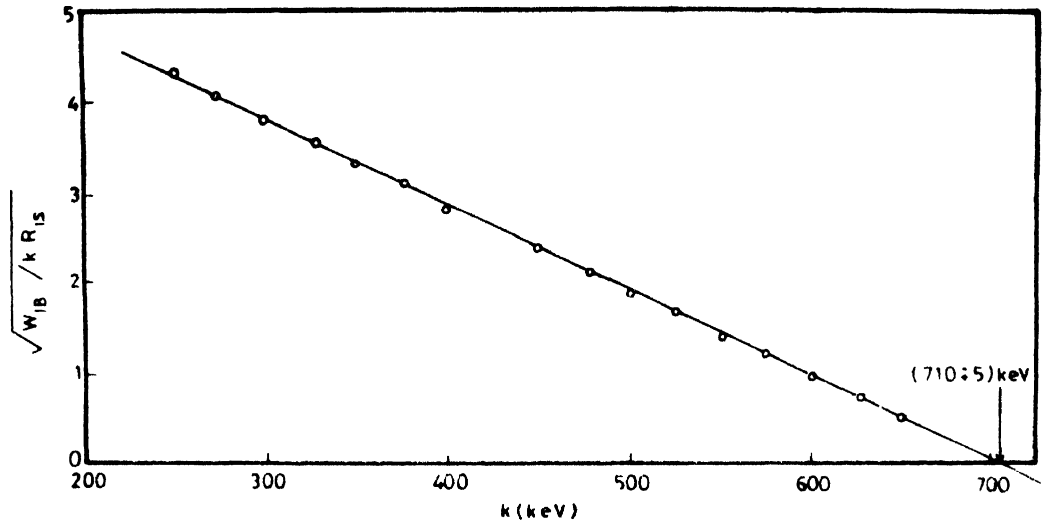

Figure 3. Jauch plot.

6. Theory

Theoretical 1S–IB distribution was evaluated using the procedure developed by Intemann (1971). The IB distribution is given by

$$\frac{dW_{1S}}{W_k}=\frac{\alpha}{\pi}\cdot\frac{k(q_{1S}-k)^2}{q_{1S}^2}\cdot R_{1S}.dk \tag{6.1}$$

where q_{1S} is the 1S end point energy and R_{1S} is correction factor.

In our calculations of the intensities, we used for Q_{EC} a value of 700.4±0.7 keV obtained from the mass tables (Wapstra and Bos 1977). The theoretical distribution evaluated using eq. (4.1) is shows in Figure 2. Numerical results of integral rates

$$N_{IB}(E_1)=\int^{Q_{EC}} W_{IB}(k)dk$$

are listed in Table 1.

Table 1. Integrated photon yield.

Range (keV)	Theoretical	Experimental
250-700	5.801×10^{-3}	5.8175×10^{-3}
300-700	4.5075×10^{-3}	4.5245×10^{-3}
350-700	$3\ 316 \times 10^{-3}$	3.332×10^{-3}
400-700	2.2735×10^{-3}	2.2855×10^{-3}
450-700	1.4195×10^{-3}	1.4285×10^{-3}
500-700	7.875×10^{-4}	8.0×10^{-4}
550-700	3.635×10^{-4}	3.78×10^{-4}
600-700	1.165×10^{-4}	1.32×10^{-4}

7. Results and discussions

The measured $1S-$IB end-point energy (710.0 ± 5.0 keV) giving the transition energy to the ground state as (846.47 ± 5.0) keV is in close agreement with the value (836.4 keV) of Wapstra and Audi (1985). The present measurement confirms that at transition energies $k \gg \alpha Z$, a simple Jauch plot can be used to determine the transition energies. The observed LB photon intensities are well in agreement with the Intemann theory over a major portion, showing the importance of Coulomb and relativistic effects on the observed intensities.

The Morrison-Schiff theory does not consider the effect of the coulomb field of the nucleus. Most of the experimental transition energy determinations have been made by linearizing the spectra and constructing a Jauch plot. The accuracy of this procedure entirely depends on how closely the investigated spectrum is approximated by Morrison-Schiff theory. Eventhough for transitions $k \gg Z\alpha$, Jauch plot is expected to yield sufficiently accurate results, the absolute IB photon intensities are expected to experience significant reduction in medium Z and heavy nuclei. While this lowering of intensity is most obvious in the heavier nucleides with $51 < Z < 80$, it can also be noted on the average in the data in light nucleides $18 < Z < 32$ (Bambynek *et al* 1977).

Our results precisely display this characteristic nature. Eventhough the transition energy estimated from Jauch plot is in agreement with the latest value of mass tables, the observed IB photon intensities are explained fairly well by the Coulomb corrected relativistic theory of Intemann (1971). Accordingly, we believe that our measurement has clearly brought out the importance of these Coulomb and relativistic effects.

Acknowledgments

One of the authors (BRSB) acknowledges the financial support received from the University Grants Commisson, India through a research scheme.

References

Babu B R S, Venkataramiah P, Gopala K and Sanjeeviah H 1985 *J. Phys.* **G11** 1213

Bambynek W, Behrens H, Chen M H, Crasemann B, Fitzpatrick M L, Ledingham K W D, Genz H, Mutterer M and Intemann R L 1977 *Rev. Mod. Phys.* **49** 77

Glauber R J and Martin P C 1956 *Phys. Rev.* **104** 158

Intemann R L 1971 *Phys. Rev.* **C3** 1

Jung R G and Pool M L 1956 *Bull. Am. Phys. Soc.* **1** 172

Jauch J M 1951 *Oak Ridge National Lab. U. ORNL-1102*

Lancman H and Lebowitz J M 1971 *Phys. Rev.* **C3** 188

Liden K and Starfelt N 1953 *Ark. Fyx.* **7** 427

Martin P C and Glauber R J 1958 *Phys. Rev.* **109** 1307

Moller C 1937 *Phys. Z. Sowjet Union* **11** 9

Morrisson P and Schiff L I 1940 *Phys. Rev.* **58** 24

Peterson B G 1965 *in Alpha-Beta and Gamma ray Spectroscopy* ed. K. Siegbahn (North Holland : Amsterdam) p 1574

Wapstra A H and Audi G 1985 *Nucl. Phys.* **A432** 44

Wapstra A H and Bos K 1977 *Atom Nucl. Data Tables* **19** 175