Radiative beta decay in $^{111}\text{Ag}$

This article has been downloaded from IOPscience. Please scroll down to see the full text article.
(http://iopscience.iop.org/0305-4616/10/4/016)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 14.139.155.135
The article was downloaded on 20/05/2013 at 10:36

Please note that terms and conditions apply.
Radiative $\beta$ decay in $^{111}$Ag

A Basavaraju, P Venkataramaiah, K Gopala and H Sanjeeviah
Department of Physics, University of Mysore, Mysore 570 006, India

Received 26 September 1983, in final form 3 November 1983

Abstract. Inner bremsstrahlung (IB) accompanying first-forbidden $\beta$ decay of $^{111}$Ag has been measured using the magnetic deflection technique with a 4.5 cm x 5.1 cm NaI(Tl) scintillation spectrometer in the energy region 100-1000 keV. The contribution to the IB pulse-height distribution from the two prominent monoenergetic gamma-ray lines emitted by the source was subtracted by constructing their spectra using peak-to-total ratios, peak-to-valley ratios and peak-to-valley separations. The raw spectrum is unfolded following the method of Liden and Starfelt and compared with the theories of KUB, Lewis and Ford (LF) and Ford and Martin (FM). The measured pulse-height distribution is found to show agreement with LF theory in the lower energy region up to 450 keV; it is found to be lower than KUB and FM theories up to 550 keV and thereafter deviates positively from all three theories.

1. Introduction

Beta decay is accompanied by certain higher-order processes such as internal ionisation, internal excitation and internal bremsstrahlung (IB). During beta emission or electron capture (EC) there is a sudden change in the nuclear charge which acts as a perturbation on the atomic orbitals. An electron in the atom may thus be excited to one of the unoccupied levels, which is generally called shake-up or internal excitation, or it may be removed to the continuum, which is generally called shake-off or internal ionisation (Feinberg 1941, Isozumi and Shimizu 1971). The outgoing electron can also cause ionisation by Coulomb scattering of an inner-shell electron (Intemann 1982).

Internal bremsstrahlung is a weak continuous energy electromagnetic radiation accompanying beta emission or orbital electron capture. In beta decay IB is emitted by the changing dipole moment of the nucleus–electron system caused by the creation and separation of the electron and proton. This should be contrasted with external bremsstrahlung (EB) produced due to the interaction of the outgoing electron with the electromagnetic field of nuclei other than that of its origin. The probability of IB emission is of the order of the fine-structure constant ($\alpha$) per emitted electron. The theory of IB in beta decay (IB($\beta$)) was developed for allowed beta transitions by Knipp and Uhlenbeck (1936) and independently by Bloch (1936) assuming the polar-vector interaction for beta decay. This so called KUB theory was extended to forbidden decay processes and corrected for Coulomb effects by many authors: Chang and Falkoff (1949), Madansky et al (1951), Nilsson (1956), Lewis and Ford (LF) (1957), Felsner (1963), Janouch and Havranek (1965), Struzynski and Pollock (1966), Gebhardt (1968) and Ford and Martin (FM) (1969).
Ford and Martin considered detour transitions in the IB process for forbidden decay processes and worked out the theory for unique first-forbidden transitions only. A detour transition is one in which the parent nucleus emits a photon and goes to a virtual intermediate state from which it subsequently beta decays to the final state of the daughter nucleus or vice versa. Many experimental investigations have been made to verify the theoretical predictions (Persson 1968). In these investigations both allowed and forbidden beta emitters have been used. It is found that the disagreement between theory and experiment in the case of IB accompanying forbidden beta decay varies from a factor of 3.3 to 9.5 (Beattie and Byrne 1971, Prasad Babu et al 1976a, b). In some of the forbidden decay isotopes the experimental IB spectra are found to deviate positively from theory at the higher-energy end of the spectrum (Narasimha Murty and Jnanananda 1967).

In order to understand the concepts involved in the various descriptions of the process, it was felt appropriate to study the IB spectrum accompanying beta decay in one more isotope ($^{111}$Ag) with forbidden transition. $^{111}$Ag is selected because there is no reference in the literature regarding its IB measurement.

2. Experimental details and procedure

$^{111}$Ag was procured from Bhabha Atomic Research Centre, Bombay, India. The source was supplied in the form of silver nitrate in dilute nitric acid solution. Thin mylar films ($\sim 1.7$ mg cm$^{-2}$) cemented to perspex rings of inner diameter 2.3 cm and outer diameter 2.5 cm were used for the preparation of sources. The sources were prepared by evaporating the liquid drop-by-drop onto the centre of the mylar film. Care was taken to ensure that uniform spreading of the source was achieved by adding a drop or two of dilute insulin. Three sources of different strengths were prepared and tested for gamma impurity by recording the spectrum for each source with a hyperpure germanium gamma-ray spectrometer. The spectra indicated that the source was free from impurities. The recorded spectra indicated two prominent gamma lines of energies 245.42 and 342.12 keV. The decay of $^{111}$Ag (figure 1) is classified as first forbidden. It has a half-life of 7.5 d. It decays (Harmatz 1979) mainly with three branching ratios: 92% of $^{111}$Ag decays to the ground state of cadmium with an end-point energy of 1028 keV, 1% of it decays with an end-point energy of 783 keV to the metastable state (85 ns) of cadmium, which goes to the ground state by emitting a 245.42 keV gamma ray, and 7.1% of it decays with an end-point energy of 686 keV to the metastable state (59 ns), which goes to the ground state of cadmium by emitting a 342.13 keV gamma ray.

Some of the earlier investigators (Persson 1968, Narasimha Murty and Jnanananda 1967, Prasad Babu et al 1974) have studied the IB spectra by stopping beta particles in a low-Z material like perspex or beryllium. In this technique EB is produced in the beta absorber in addition to the absorption of IB in it. Corrections are to be applied for these. In the present investigation the magnetic deflection technique was employed and the production of EB and absorption of IB in the beta stopper have been totally eliminated.

The experimental arrangement, the description of the set-up and the procedure adopted for the present investigation are given elsewhere (Venkataramaiah et al 1977).

The IB spectra of three sources of strengths 79, 96 and 110 $\mu$Ci were recorded. The spectral distribution beyond the gamma-ray lines was found to be unchanged. This indicates that the contribution of EB produced in the source was negligible. A 4.5 cm x 5.1 cm NaI(Tl) crystal mounted on an RCA 8053 photomultiplier coupled to a 256-channel analyser was used in the present investigation. The spectrometer was calibrated...
Radiative $\beta$ decay in $^{111}\text{Ag}$

using the following gamma-ray lines: $^{170}\text{Tm}$ (84 keV), $^{57}\text{Co}$ (122 keV), $^{141}\text{Ce}$ (145 keV), $^{203}\text{Hg}$ (279 keV), $^{51}\text{Cr}$ (320 keV), $^{113}\text{Sn}$ (392 keV), $^{22}\text{Na}$ (511 keV), $^{137}\text{Cs}$ (662 keV), $^{54}\text{Mn}$ (835 keV) and $^{60}\text{Co}$ (1173 keV). The source-to-detector distance was 24.6 cm. The $\text{IB}$ spectrum was recorded for over 10 h. The stability of the counting system was maintained by checking it before and after the experiment with the 342 keV gamma-ray line in the experimental source and the 662 keV $^{137}\text{Cs}$ gamma-ray line. Since $\text{IB}$ is of very low intensity, the source-dependent background was recorded for the same time before and after each measurement. The data were recorded over several runs. The time was recorded from the start in each and every trial. The decay correction was made in each trial by taking into account the time elapsed from the start of the first trial. This correction was made to normalise the measured spectrum to the source strength at the start. The average of ten consistent readings was considered for the final evaluation of the spectrum.

3. Data analysis

The recorded spectrum is the true spectrum folded with the response function of the
detector. In order to obtain the true IB spectral distribution the raw spectrum should be unfolded. As a first step the background was subtracted from the measured spectrum. The two gamma lines of energies 245 and 342 keV are superposed upon the IB spectrum below 400 keV (figure 2). Because of the presence of these monoenergetic lines the 'pile-up' contribution to the recorded IB spectrum has been considered.

The 'pile-up' consists of the random coincidences of two uncorrelated radiations being detected within the resolving time $2\tau$ of the detector system. The pile-up at any energy $E$, as given by Van Lieshout et al (1968), is

$$N_{pu}(E) = 2\tau \int_0^E N(E-X)N(X) \, dX$$

(1)

where $N_{pu}(E)$ represents the number of pulses per second at energy $E$ due to the combined contribution from the pairs of pulses at energies $(E-X)$ and $X$ occurring within the

\[ \text{Figure 2. Experimental pulse-height (O), background (●) and Compton electron (---) distributions as a function of energy.} \]
resolving time $2\tau$. The pile-up spectrum will have a sum peak at double the energy of the photopeak energy with a total intensity of $2\tau N^2$ where $N$ is the count rate in the photopeak. This can be used to find $\tau$. Using sources of $^{203}$Hg, $^{137}$Cs and $^{54}$Mn of moderate strength and accumulating the data for over $10^4$ s several times in the multichannel analyser, the resolving time $2\tau$ of the detector system was found to be $(6.56 \pm 0.26) \mu$s.

Using the experimental spectrum of $^{111}$Ag, the contribution due to pile-up at each channel was obtained by integrating equation (1) numerically. Since the source strength used was low (96 $\mu$Ci) the pile-up contribution was found to be negligible. After the above two corrections, the IB spectrum was corrected for the two gamma-ray lines. The following procedure was followed for the construction of the gamma-ray spectra of these two lines. Gamma-ray spectra of $^{57}$Co (122 keV), $^{141}$Ce (145 keV), $^{203}$Hg (279 keV), $^{51}$Cr (320 keV), $^{113}$Sn (392 keV), $^{22}$Na (511 keV), $^{137}$Cs (662 keV), $^{54}$Mn (834 keV) and $^{65}$Zn (1114 keV) were recorded using the same experimental set-up and geometry. With these spectra the peak-to-valley ratios and peak-to-valley separations were determined. The energy dependences of the peak-to-valley ratios and peak-to-valley separations were established (figure 3). A third-degree polynomial was fitted to the left half of the valley before the photopeak and the energy dependence of the coefficients was established. By locating the peak positions a simple gaussian was fitted and the peak areas were computed. The Compton contribution of these two lines was assumed to be flat up to their Compton edges. Using the above factors, the spectra of the two lines were constructed. Then the numbers due to the two lines at the corresponding channels were added and then

![Figure 3](image-url)

**Figure 3.** (a) Variation of the peak-to-valley ratio with energy: $P$, count rate at photopeak; $V$, count rate at valley. (b) Variation of the peak-to-valley separation with energy: $E_p$, energy corresponding to the peak; $E_v$, energy corresponding to the valley.
subtracted from the background- and pile-up-corrected experimental spectra. Further, corrections for backscattering, finite energy resolution, the Compton electron distribution shown in figure 2 and the gamma detection efficiency including geometry were made following the method of Liden and Starfelt (1953).

4. Comparison with theory

$^{111}$Ag has three main beta branches with different end-point energies. The theoretical calculations of the $\beta$ spectral distribution were carried out separately for these branches and the corresponding numbers were added by considering the branching ratios in order to evaluate the total spectrum. The unfolded absolute $\beta$ spectrum is represented as number of photons.

![Figure 4. Comparison of the experimental $\beta$ spectrum (O) with (A) the KUB, (B) the LF and (C) the FM theoretical distributions.](image)

Figure 4. Comparison of the experimental $\beta$ spectrum (O) with (A) the KUB, (B) the LF and (C) the FM theoretical distributions.
photons per MeV per beta disintegration as a function of energy along with the theoretical distributions of KUB, Lewis and Ford (LF) and Ford and Martin (FM) in figure 4.

4.1. Error analysis

The percentage errors involved in the present measurement and the various corrections applied to the measured spectrum are shown in table 1. The correction due to backscattering is found to be negligible, and thus the error from this source is not shown in the table. In the lower-energy region, of all the errors, except the error due to source strength, the error involved in the subtraction of the two gamma-ray lines becomes most significant. In the measured IB spectrum the overall error is less than 12% in the lower-energy region and it is about 16% in the higher-energy region.

5. Results and discussion

The experimental IB results are compared with the theoretical distributions of KUB (allowed), Lewis and Ford (forbidden) and Ford and Martin (detour). The experimental results in the lower-energy region from 100 to 450 keV are close to the theoretical distribution of LF, between 450 to 650 keV the results are lower than the KUB and FM distributions and then they deviate positively from all the theories. This trend is similar to the earlier IB measurements (Narayana et al 1976, Basavaraju et al 1983) exhibiting forbidden character. However the present results show agreement with the first-forbidden theoretical distributions of Lewis and Ford in the energy range 100–450 keV. The present theories fail to account for this positive deviation in the higher-energy region of the spectrum. This trend is hard to understand from the known characteristics of the IB phenomenon.

Acknowledgments

The authors thank Dr B Sanjeevaiah, Head of the Department of Physics, for providing facilities for the investigation. One of the authors (AB) thanks the University Grants Commission (India) for a fellowship under the Faculty Improvement Programme (FIP).
References

Beattie R J D and Byrne J 1971 Nucl. Phys. A 161 650
Bloch F 1936 Phys. Rev. 50 272
Chang C S and Falkoff 1949 Phys. Rev. 76 365
Feinberg E L 1941 Sov. J. Phys. A 4 423
Felsner G 1963 Z. Phys. 174 43
Gebhardt D 1968 Nucl. Phys. A 107 593
Harmatz B 1979 Nuclear Data Sheets 27 453
Knipp J K and Uhlenbeck G E 1936 Physica 3 425
Liden K and Starfelt N 1953 Ark. Fys. 7 427
Madansky L, Lipps F, Bolgiano P and Berlin T H 1951 Phys. Rev. 84 596
Nilsson S B 1956 Ark. Fys. 10 467
Struzynski R E and Pollock F 1966 Nucl. Phys. 79 113