Inner Bremsstrahlung Accompanying the Non-Unique First Forbidden β-Decay of ^{141}Ce

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The inner Bremsstrahlung (I.B.) spectrum accompanying the β-decay of ^{141}Ce (non-unique first forbidden β-transition) was measured using a single channel scintillation spectrometer. The measured I.B. was analyzed by the variable width peeling-off method. This analyzed and corrected I.B. was compared with those calculated according to the original theories of Knipp and Uhlenbeck as well as of Bloch (KUB), the coulomb corrected theories of Lewis and Ford and of Nilsson, and according to detour-transition calculations of the Ford and Martin theory. Ths shape correction factor suggested by Konopinski and Uhlenbeck on the Fermi β-decay theory was applied to the calculated I.B. based on Nilsson's theory (modified KUB theory). The experimental results are in better agreement with the modified KUB theory than the other theories.

Introduction

Inner Bremsstrahlung (I.B.) is a weak continuous energy electromagnetic radiation accompanying β-emission and electron capture. When a nucleus emits an electron, the dipole moment of the nucleus-electron system changes due to the sudden creation and escape of an electron from a proton causing the emission of I.B. The importance of I.B. studies, both from an experimental and theoretical standpoint, is highlighted in a detailed survey by Persson [1]. Several discrepancies exist not only between theory and experimental, but also among the individual measurements. Several authors have worked out the theory to describe I.B. Knipp and Uhlenbeck [2] and Bloch [3] (KUB) developed the theory for allowed transitions using the Fermi polar vector interaction for β-decay without taking into consideration the effect of the coulomb field of the nucleus. Modifications of the theory have been worked out, taking into account coulomb effects, by Nilsson [4] and Lewis and Ford [5] (LF). Disagreement between theory and experiment is more conspicuous in the case of forbidden transitions [6]. The divergence between experiment and theory is found to increase with increasing energy. Attempts to include detour effects [7] also have not yielded satisfactory results.

The I.B. spectrum accompanying the non-unique first forbidden β-decay of ^{141}Ce was measured before by Gundu Rao and Sanyeeviah [8] in the energy range 200–560 keV with an NaI (TL) scintillation spectrometer. In their investigation the I.B.-spectrum was recorded in the energy region 0 to 580 keV, but for the final analysis it was restricted to the region above 200 keV because of the presence of the 145 keV monoenergetic γ-component. The corrected distribution is compared with the direct and detour theories of Lewis and Ford [5] and Ford and Martin [7]. Total disagreement between experiment and theory was observed over the entire region of the investigated spectrum. We have measured the I.B. of ^{141}Ce before [9], but still there remained some deviations between experiment and theory.

In the present work new calculations were carried out, based in applying the shape correction factor C_1 for the first forbidden β-transition to the theory of Nilsson (where in Nilsson's theory the coulomb correction factor was considered in a more refined manner than in other theories). This is called modified KUB theory, where C_1 is calculated according to the following equation suggested by Konopinski and Uhlenbeck [10, 11]:

$$C_1 = P^2 + q^2 = (W^2 - 1) + (W_0 - W)^2 ,$$

where P and q are the moments of the associated electron and neutrino, while W is the energy of the electron and W_0 the maximum energy release in units of $m_0 c^2$.

Therefore it was decided to reinvestigate the I.B. spectrum of ^{141}Ce to provide an extensive and rigorous check on the modified KUB calculations. As

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a result, good agreement between the experimental data and the modified KUB calculations in a wide energy range was obtained. Furthermore, the experimental results were compared with the aformentioned theories of KUB [2, 3], Lewis and Ford [5], Nilsson [4] and Ford and Martin [7].

Experimental

^{141}Ce performs a non-unique first forbidden β-transition [8] with two β-energies of 0.581 MeV and 0.436 MeV with branching ratios 30% and 70%, respectively. The latter β-group feeds the first excited state of ^{141}Pr nuclei followed by a gamma transition of 0.145 MeV, while the 0.581 MeV β-group from ^{141}Ce feeds the ground state of ^{141}Pr nuclei. The ^{141}Ce source, prepared in Labo. des products Biomedicaux C.E.N. Saclay, was obtained in a bottle containing 0.4 ml of 5 μci activity. A known quantity of the solution was evaporated, drop by drop, on a thin alluminated film mounted on a perspex ring of 1 cm inner diameter. Care was taken to have a uniform spread using a drop or two of a dilute aqueous solution of insulin, and the extent of the source was limited to a circular area of 0.6 cm diameter.

The I.B. spectrum was measured with a scintillation gamma spectrometer as described in detail in [12, 15]. A NaI (Tl) crystal of 2.5 cm diameter and 1.997 cm height was optically mounted to a photomultiplier tube (type 56 AVP), and the pulses were differentiated by a single channel analyzer. The energy resolution of the whole γ-spectrometer was determined to be 12%. The NaI (Tl) crystal-efficiency was calculated for different photon energies and checked experimentally. The raw I.B. spectrum of ^{141}Ce, which was obtained directly from the scintillation spectrometer, is shown in Figure 1. In order to remove the gamma line (0.145 MeV) contribution and obtain the pure I.B. spectrum, two approaches were performed: The first one is based on applying a least squares fit for energies above that of the gamma-line up to the end-point, after plotting the pulse height distribution multiplied by the corresponding photon energy on a semilogarithmic scale. By extrapolation of the expected straight line (as a result of the exponential character of the I.B. spectrum [16]), the pure I.B. spectrum was obtained as shown by the full curve in Figure 2. The second approach was suggested by Narasimha Murty and Jnananda [17]. It is based on choosing a monoenergetic source with a gamma-line energy equal to that of the source under investigation, measuring its spectrum under the same condition and geometry as the I.B. spectrum and subtracting it from the raw I.B. The pure I.B. spectrum obtained as a result of using the second approach is shown by the broken curve in Figure 2. It is clear from this figure that the two approaches lead to the ame result within the experimental errors.

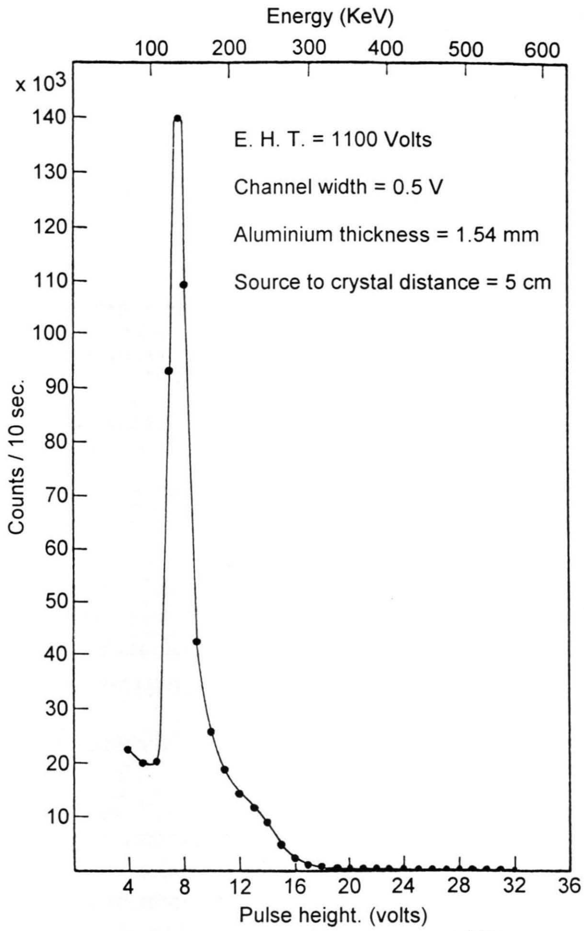

Fig. 1. Raw inner bremsstrahlung spectrum of ^{141}Ce.

In order to determine the probability of I.B., the next few steps were:

1) The pure I.B. spectrum is analysed into its constituent photons using the peeling off method, which implies the compton distribution and finite energy resolution correction.
2) The area under the photopeak of each of the obtained photons is then calculated.
3) This area is then corrected for crystal efficiency, solid angle, back scattering, external bremsstrah-

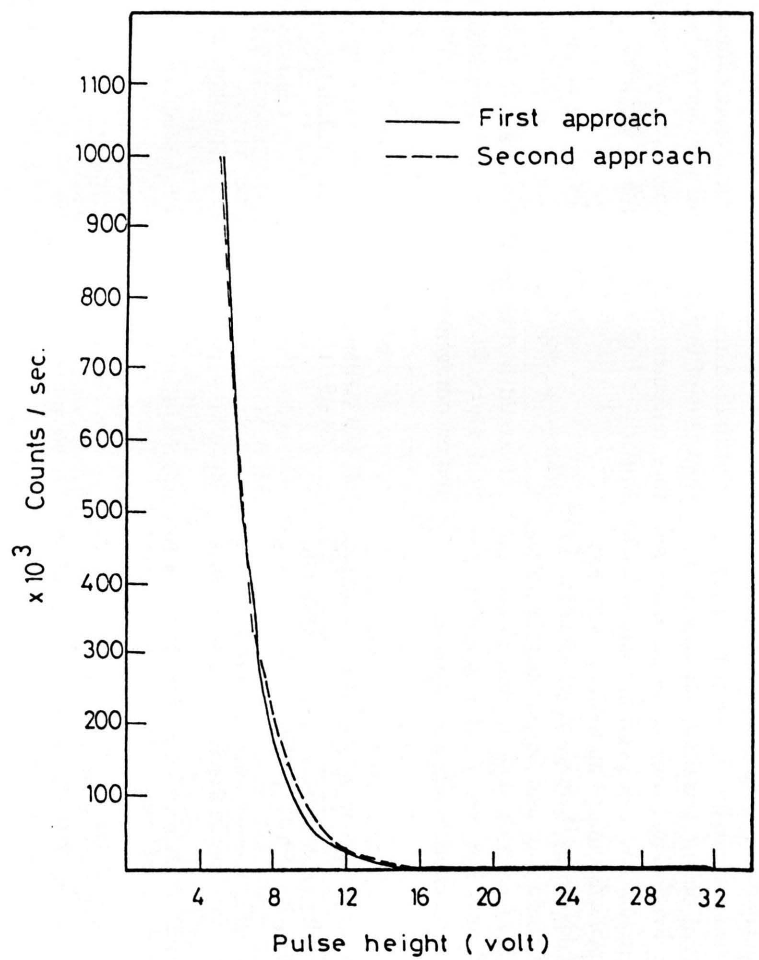

Fig. 2. Pure inner bremsstrahlung spectrum of ^{141}Ce, free from mono-energetic gamma line contributions, obtained by the two approaches.

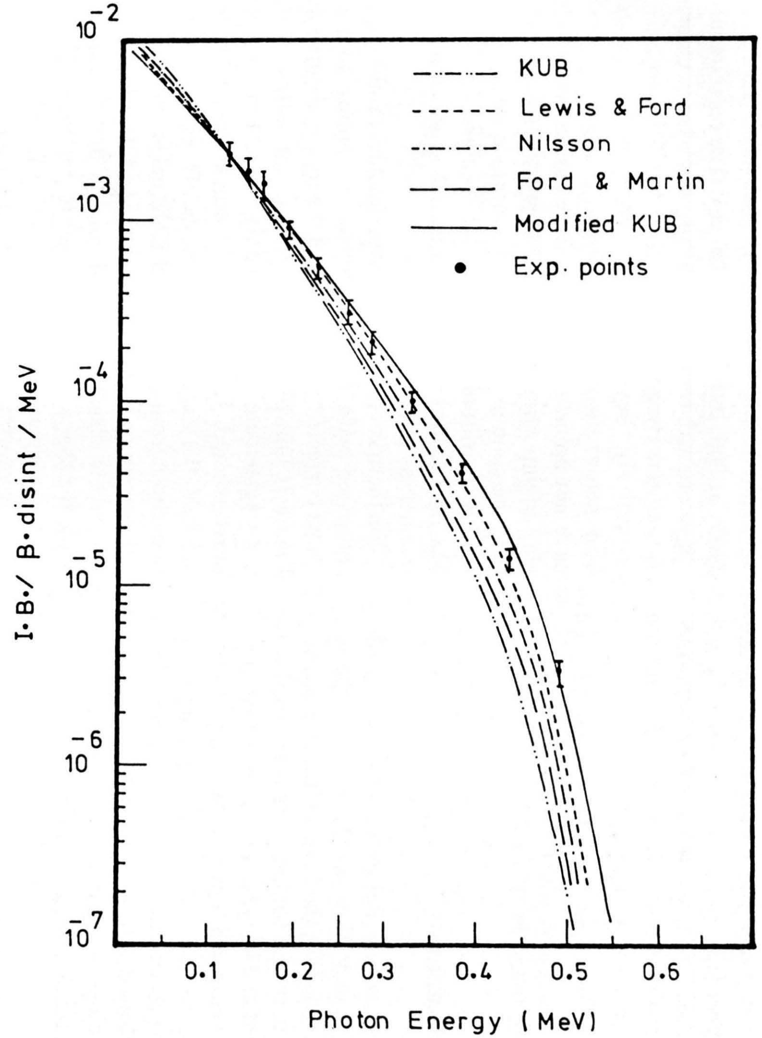

Fig. 3. Experimental inner bremsstrahlung probability of ^{141}Ce and those calculated according to KUB, Lewis and Lord, Nilsson, Ford and Martin, and modified KUB theories.

lung, iodine K-X-ray and absorption in the aluminum-stopper [12].

4) Division by the β-source activity is then performed to get the probability of I.B. per β-disintegration per MeV as shown in Figure 3.

The details of the experimental arrangements and all necessary corrections which were applied for the pure I.B. can be found in [12–15].

Results and Discussion

The present experimental results of the I.B. probability per β-disintegration per MeV in comparison with that calculated on the basis of allowed β-transitions (KUB theory and coulomb corrected theories of Lewis and Ford and of Nilsson) are presented in Figure 3. The investigated energy was from 133 keV. From Fig. 3 one observes that there is a disagreement between the experimental result and these theories on the basis of allowed β-transitions. This disagreement is attributed to the fact that, while the first forbidden radio-nuclei emit β-spectra analogous to the allowed ones, their I.B. spectra differ from that of allowed β-transition nuclei.

Therefore the experimental results were compared with those calculated according to the Ford and Martin theory (dashed curve in Fig. 3), in which the degree of forbidden and detour transition was taken into consideration. From Fig. 3 one observes that the experimental results are in a good agreement with Ford and Martin calculations up to 438 keV photon energy. Above this energy there is a slight deviation. In the paper of Gundu Rao and Sanjeeviach [8], total disagreement between their experimental values and theories was found. For instance, the deviation between their experimental results and Lewis and Ford calculations was found to be 5%, 21%, 57% and 170% at 200, 250, 300 and 350 keV. The corresponding values with respect to the Ford and Martin theory at the same energies were 55%, 50%, 37% and 11%, respectively. Beyond 400 keV their results deviate from detour theory by over 100%. Probably they [8] have not applied all the necessary corrections which play an important part in the I.B. measurements. Further, the coulomb effect and the forbiddence effect on the I.B. distribution in Lewis and Ford and Ford and Martin theories are not considered in an accurate manner, as mentioned before.

Furthermore, the present experimental results were compared with those calculated according to the shape corrected modified KUB theory (solid curve in Figure 3). One observes that the present results are in close agreement with that theory over all the energy range studied. However, in the energy range 333 to 438 keV the experimental results are slightly lower than those from the modified KUB calculations. This difference may be attributed to the fact that the ^{141}Ce β-decay is classified as non-unique first forbidden while the shape correction factor (C_1) in the modified KUB theory was calculated as a first forbidden type.

Therefore, the above study may lead to the previously reported conclusion [13, 14] that, if the effect of coulomb correction, degree of forbiddence and detour contribution are considered in a more refined manner than that of the aforementioned theories, a satisfactory agreement between experiment and theory, particularly at high energies, can be expected.

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[1] B. Persson, Proceedings of the conference on Higher order process in Nuclear decay, vol. 2, Budapest 1968.
[2] J. K. Knipp and G. E. Uhlenbeck, Physica **3,** 425 (1936).
[3] F. Bloch, Phys. Rev. **50,** 272 (1936).
[4] S. B. Nilsson, Arkiv Phys. **10,** 467 (1956).
[5] R. R. Lewis and G. W. Ford, Phys. Rev. **107,** 756 (1957).
[6] D. G. S. Narayana and K. Narasimhamurty, Z. Phys. **A 283,** 145 (1977).
[7] G. W. Ford and C. F. Martin, Nucl. Phys. **A 134,** 47 (1969).
[8] K. S. Gundu Rao and H. Sanjeeviah, Nucl. Phys. **A 376,** 478 (1982).
[9] S. El-Konsol, A. M. Basha, E. I. Khalil, and S. A. Gaafer, Egypt. J. Phys. **14,** No. 1, 1 (1983).
[10] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **48,** 7 (1935).
[11] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **60,** 308 (1941).
[12] E. I. Khalil, Thesis submitted for M.Sc. degree in physics, Faculty of Science, Cairo University 1981.
[13] A. M. Basha, E. I. Khalil, M. Hussein, H. S. Ragab, and S. El-Konsol, Z. Phys. **A 338,** 3 (1991).
[14] A. M. Basha, E. I. Khalil, M. Hussein, and H. Ragab, Indian J. Phys. **65 A 2,** 120 (1991).
[15] S. El-Konsol, A. M. Basha, E. I. Khalil, and S. A. Gaafer, Egypt. J. Phys. **13,** 35 (1982).
[16] M. G. Mayer, S. A. Moszkowski, and L. W. Nordheist, Rev. Mod. Phys. **23,** 315 (1954).
[17] K. Narasimha Murty and S. Jnananda, Proc. Phys. Soc. **90,** 109 (1967).