PHYSICAL REVIEW C VOLUME 39, NUMBER 1 JANUARY 1989

Internal bremsstrahlung spectrum of ^{35}S in the range from 10 to 100 keV

N. M. Badiger and N. Umakantha
Department of Physics, Karnatak University, Dharwad, 580 003, India
(Received 2 June 1988)

The internal bremsstrahlung spectrum of ^{35}S has been measured in the range from 10 to 100 keV. The magnetic deflection method is adopted for preventing the production of external bremsstrahlung in the detector. The measured spectrum agrees well with the Knipp-Uhlenbeck-Bloch and the Coulomb-corrected Knipp-Uhlenbeck-Bloch theories only in the range from 10 to 50 keV, but agrees well with the Vinh-Mau theory in the entire range from 10 to 100 keV.

I. INTRODUCTION

Beta decay is accompanied by the emission of a weak and continuous electromagnetic radiation known as internal bremsstrahlung (IB). This is due to changing of dipole moment of the nucleus-electron system caused by creation and separation of the electron and the proton. This is a second-order process, and hence the probability of emission of IB is proportional to α, the fine-structure constant. The IB spectrum is continuous, extending up to the end-point energy of the beta spectrum; the intensity decreases with the increase in photon energy. IB is to be contrasted with external bremsstrahlung (EB) produced by the deflection of the beta particles in the Columb field of a nucleus other than its own. Internal bremsstrahlung has been a subject of both experimental[1–3] and theoretical[4–11] study over the past four decades. Extensive experimental observations have been made in the range from above 50 keV.[12–14] All the measurements have been made using NaI(Tl) scintillation detectors which are known to have poor energy resolution in the low-energy region. This leads to appreciable error in evaluating the true spectrum in the low-energy region from the experimentally observed pulse height distribution. Though detectors with high resolution at low energy have become available in the form of Ge(Li) and HPGe detectors, only one research group has so far made measurements taking advantage of this improvement in the detector resolution.[15,16] Similarly, starting from the first theoretical evaluation by Knipp and Uhlenbeck,[4] and independently by Bloch,[5] many improved theoretical evaluations have been made over the years by various authors.[6–11] Further, it is found that even over the low-energy region of 10–100 keV, the various theoretical estimations do not agree with one another and similarly there is also disagreement between experimentally measured spectra.[12,13,17,18] In fact, even in the case of ^{35}S, which is best suited for comparing experimental and theoretical spectra (because of its low Z value and low end-point energy), all earlier research groups[12,13,17,18] which used NaI(Tl) detectors reported disagreement between theory and experiment, whereas only one latter group[15,16] which used a Ge(Li) detector reported good agreement with Vinh-Mau theory. In view of this, we determined the IB spectrum of ^{35}S in the energy range from 10–100 keV using a HPGe detector. The importance of measuring IB spectrum of ^{35}S has been discussed by Beryeni *et al.*[16]

II. EXPERIMENTAL ARRANGEMENT

The experimental arrangement we used for measuring IB is shown schematically in Fig. 1. The IB photons from a source S were collimated by means of a set of three perspex collimators C_1, C_2, C_3 (each 1 cm thick) and a lead collimator (4.5 cm thick) and made to fall on a HPGe detector D. The output pulses were amplified and recorded in a 1024 channel multichannel analyzer.

A carrier free radioactive ^{35}S source in the form of H_2SO_4 in dilute HCl, was obtained from Bhabha Atomic Research Centre, Bombay, India. The source was prepared by evaporation on a 500 $\mu g/cm^2$ thin VYNS foil and covered with a 25 $\mu g/cm^2$ thin VYNS foil. The strength of the source was 700 μC spread over an area of 5 mm diameter.

In measuring the IB spectrum from a beta source we should prevent the beta particles from producing EB in the surrounding material and in the detector. In general, three methods are adopted for achieving this. In the beta absorption method a low-Z absorber, such as beryllium or perspex, is placed between the source and the detector to absorb all beta particles, with negligible production of EB in the absorber. In this method IB is also attenuated and a correction becomes necessary; this correction is geometry dependent. In the coincidence method, the IB photon is detected in coincidence with the beta particle in an arrangement such that the EB photon produced by the beta particle in the beta detector cannot reach the IB photon detector. Though this method is desirable in principle, in practice it needs collection of data for very long time. In the magnetic deflection method a magnetic field is introduced between the source and the IB detector to deflect the beta particles away from the detector. These deflected beta particles are absorbed in low-Z material, and whatever EB is produced is prevented from reaching the detector by placing gamma absorbers suitably. Normally an electromagnet is used to produce the magnetic field.

In our experiment we adopted the magnetic deflection method using permanent magnets (M). A set of four

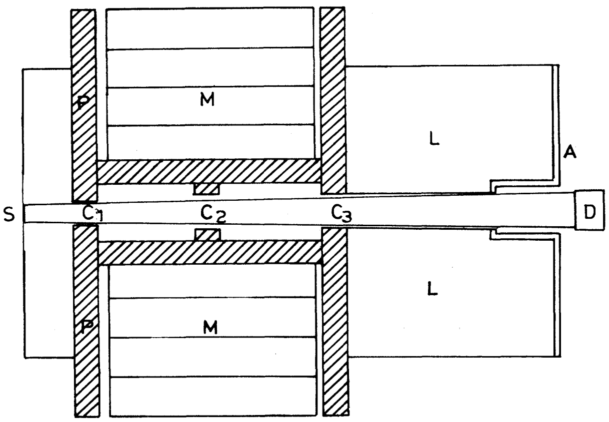

FIG. 1. Schematic experimental arrangement (not to scale). *S*: source; *D*: HPGe detector; C_1, C_2, and C_3: perspex collimators; *L*: lead shielding; *P*: perspex frame; *M*: permanent magnets; and *A*: aluminium lining.

magnets were placed, as shown in Fig. 1, on either side of the photon beam between the collimators C_1 and C_3. Each permanent magnet was of the size 4.5 cm×4.5 cm×2.5 cm, and together they produced a magnetic field of about 1000 G over a length of 5 cm. It was found experimentally that the count rate due to beta particles transmitted through C_3, as detected by a Geiger counter, decreased to background count rate when magnets were placed on either side of the beam, indicating that the beta particles could not reach the HPGe detector in our experiment. Further the EB produced by the deflected beta particles in perspex was absorbed in the lead collimator *L*. The lead collimator was lined with 2 mm thick aluminum sheet *A* to absorb lead x rays.

We used a 7 mm thick, 11 mm diameter EG&G ORTEC 10/80/17 high purity germanium (HPGe) detector. In order to reduce the leakage current and the noise from the field effect transistor amplifier, the detector material, as well as the first stage of preamplifier, was cooled to liquid nitrogen temperature. The output of the preamplifier was amplified by an amplifier (ORTEC 572) and fed to a 1024 channel multichannel analyzer through an analog-to-digital converter (TN 1241). The detector system was calibrated to have 100 eV/channel by making use of monoenergetic gamma rays of ^{241}Am.

We recorded the counts as a function of energy for sufficiently long time so that the statistical fluctuation in count rate was less than 2% at 100 keV. The background counts were also collected for the same duration of time and subtracted from the total counts to get background corrected count rate due to IB.

III. TREATMENT OF EXPERIMENTAL DATA

For comparing the experimentally recorded IB spectrum with a theoretically evaluated spectrum, the experimental spectrum should be corrected for the following: (1) the dead time of the detector, (2) the finite energy resolution of the detector, (3) the Compton electron distribution, (4) the photoelectric efficiency of the detector, and (5) the escape of germanium *K* x rays from the detector.

Normally the true experimental IB spectrum is found by adopting the method of Liden and Starfelt.[19] In this method, as the count rates at the higher-energy end of the spectrum are small and subject to large statistical fluctuation, the measured spectrum is first extrapolated to the end-point energy. Then the contribution of the Compton electrons to low-energy channels from each band of monoenergetic IB photons is calculated and subtracted stepwise starting from the end-point energy. In our case we determined IB spectrum only up to 100 keV, though the spectrum extends, in principle, up to 167 keV. So the method of Liden and Starfelt cannot be used in our case. We used a different method for comparing experimental results with the results expected according to various IB theories.

We determined from the experimentally observed pulse height distribution, the electron energy distribution in the

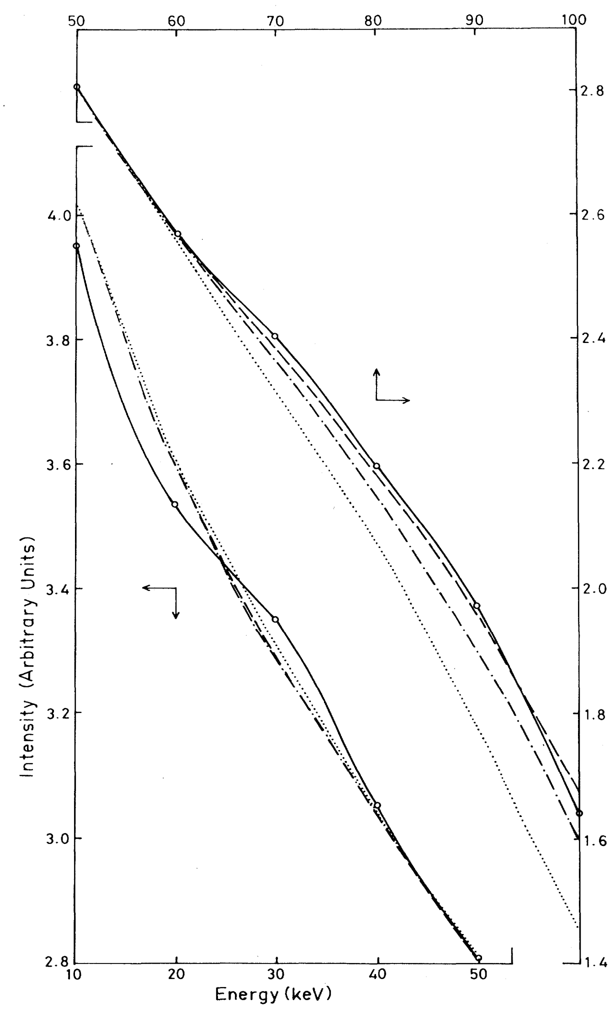

FIG. 2. Comparison of experimental spectrum of electrons produced in the detector by IB photons with various theories. Experimental values are shown by (○—○), Knipp, Uhlenbeck, and Bloch (· · ·), Spruch and Gold (– · –), and Vinh-Mau (— — —).

detector by correcting the experimental spectrum for the finite resolution of the detector and for the escape of Ge x rays, the correction for finite time resolution of the detector system being negligible. It was found that the correction for finite energy resolution hardly changed the spectrum. We used the data of Fioratti and Piermatti[20] for making the correction for escape losses. This correction was noticeable only below 50 keV and amounted to about 2% even at 10 keV.

Similarly, we evaluated from the IB spectrum expected according to each of the various IB theories, the energy spectrum of the electrons (photoelectric plus Compton) produced in the detector. We used numerical values of intrinsic efficiency and the peak-to-total ratio reported by Waino and Knoll[21] interpolated for the thickness of our detector. It was found that over the entire spectral region of interest the contribution of Compton electrons was a small fraction of the total and, in fact, even at 10 keV the contribution of Compton electrons was found to be about 1% of the total. We have compared the experimentally determined electron energy spectrum with the theoretically expected electron energy spectra in Fig. 2. For the sake of simplicity we are comparing the intensities at typical energies only. Since the contribution from the Compton electrons is very small, we are essentially comparing the energy spectrum of photoelectrons produced in the detector by the incident IB photons.

IV. RESULTS AND DISCUSSION

In the case of ^{35}S all IB theories, Knipp, Uhlenbeck, and Bloch, Lewis and Ford, Spurch and Gold, Vinh-Mau, and Struzynski and Pollock, predict the same spectrum in the energy range from 10 to 50 keV. From Fig. 2 we see that our experimentally evaluated intensities, normalized at 50 keV, agree well with theoretically evaluated intensities. On the other hand, in the range from 50 to 100 keV the theories of Vinh-Mau, Struzynski, and Pollock, and Gebhardt predict the same IB spectra, whereas theories of Knipp, Uhlenbeck, and Bloch, Lewis and Ford, and Spruch and Gold predict slightly different spectra with slightly lower intensities compared to earlier theories. We see that our experimentally determined intensities are higher than the intensities evaluated according to Knipp-Uhlenbeck-Bloch theory, but agree well with the results of other three theories. We may repeat that Meszaros *et al.* who used a Ge(Li) detector, found agreement between their experimental spectrum and theoretical spectra of Vinh-Mau, Struzynski and Pollock, and Gebhardt, whereas all the earlier investigations using NaI(Tl) detectors did not agree with one another and did not agree with the theory in the range above 50 keV. In conclusion, we state that to obtain a correct theoretical spectrum one has to take into account the Coulomb correction and to obtain a dependable experimental spectrum one has to use high-resolution (germanium) detectors.

ACKNOWLEDGMENTS

The authors wish to thank S. S. Kapoor, Bhabha Atomic Research Centre, Bombay, for providing the HPGe detector system. One of us (N.M.B.) is grateful to the Department of Atomic Energy, Government of India, for a research Fellowship.

[1]B. I. Persson, in *Proceedings of the Conference on Electron Capture and Higher Order Process in Nuclear Decay, Debrecen, 1968*, edited by D. Berenyi (Eotvos Physical Society, Budapest, 1968), Vol. 2, p. 142.
[2]F. T. Avignone III and W. C. Barker, Phys. Rev. C **26**, 2658 (1982).
[3]B. R. S. Babu, A. Basavaraju, P. Venkataramaiah, K. Gopal, and H. Sanjeevaiah, Phys. Rev. C **32**, 1010 (1985).
[4]J. K. Knipp and G. E. Uhlenbeck, Physica **3**, 425 (1936).
[5]F. Bloch, Phys. Rev. **50**, 272 (1936).
[6]R. R. Lewis, Jr. and G. W. Ford, Phys. Rev. **107**, 756 (1957).
[7]L. Spruch and W. Gold, Phys. Rev. **113**, 1060 (1959).
[8]R. Vinh-Mau, Nuovo Cimento **19**, 609 (1961).
[9]G. Felsner, Z. Phys. **174**, 43 (1963).
[10]R. E. Struzynski and F. Pollock, Nucl. Phys. **79**, 113 (1966).
[11]D. Gebhardt, Nucl. Phys. **A107**, 593 (1968).
[12]M. S. Pawar and M. Singh, J. Phys. G **2**, 43 (1976).
[13]K. Prasad Babu, K. Narasimhamurthy, and V. A. Narasimhamurthy, J. Phys. G **2**, 33 (1976).
[14]D. Berenyi and D. Varga, Nucl. Phys. **A138**, 685 (1969).
[15]S. Meszaros, Cs. Ujhelyi, D. Berenyi, and D. Varga, Nucl. Phys. **A281**, 207 (1977).
[16]D. Berenyi, S. Meszaros, D. Varga, and Cs. Ujhelyi, Nucl. Phys. **A237**, 215 (1975).
[17]N. Starfelt and N. L. Svantesson, Phys. Rev. **97**, 708 (1955).
[18]H. Longevin-Joliot, Ann. Phys. (Paris) **2**, 16 (1957).
[19]K. Liden and N. Starfelt, Ark. Fys. **7**, 472 (1953).
[20]M. P. Fioratti and S. R. Piermatti, Nucl. Instrum. Methods **96**, 605 (1971).
[21]K. M. Waino and G. F. Knoll, Nucl. Instrum. Methods **44**, 213 (1966).