PHYSICAL REVIEW C VOLUME 13, NUMBER 3 MARCH 1976

Internal Bremsstrahlung spectra from ^{185}W and ^{32}P

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(Received 23 October 1974; revised manuscript received 8 December 1975)

The internal bremsstrahlung spectra from the β decay of ^{185}W and ^{32}P were measured using a NaI(Tl) scintillation spectrometer with a standard geometrical arrangement. After making all the necessary corrections the experimental results are compared with the allowed theory of Knipp, Uhlenbeck, and Bloch (KUB theory) and also with the Coulomb corrected theories of Lewis, Ford, and Nilsson. In the case of ^{185}W it is found that from 78 to 200 keV the experimental distribution is in good agreement with the KUB theory, whereas beyond 200 keV and below 78 keV the experimental points are far above even the highest Coulomb corrected theoretical distribution of Nilsson. The internal bremsstrahlung from this isotope has not been previously investigated. In the case of ^{32}P the experimental relative intensity spectrum is compared with the KUB theory and also with the Coulomb corrected theory of Lewis and Ford. Fairly good agreement is obtained from 30 to 200 keV with the KUB theory but in the energy region from 200 to 900 keV, the experimental results deviate positively from both the KUB and Lewis and Ford theories. The experimental excess over the Lewis and Ford theory is 15% on the average.

[RADIOACTIVITY ^{185}W, ^{32}P; measured internal bremsstrahlung spectrum.]

INTRODUCTION

A number of experimental and theoretical investigations have been made of the phenomenon of internal bremmstrahlung (IB). Experimental results have been obtained for allowed as well as for forbidden β transitions (both unique and nonunique). From the literature in the field of IB (see the recent survey of Persson[1]) it is evident that despite numerous experimental and theoretical studies of IB there exist various disagreements not only between theory and experiment but even among the individual experiments; hence this field cannot be considered a closed one. For this reason we have undertaken the experimental investigation of IB from ^{185}W and ^{32}P. No reference to the study of IB from ^{185}W was found in the literature; hence it was hoped that the present study would yield new and interesting results in that it represents the first investigation of IB from this isotope.

Experimentally, the IB spectrum from ^{32}P has been the most frequently studied of all, the number of published articles being more than 15. A detailed account of experimental results and their comparison with theory has been furnished in the earlier articles.[2-21] Although in some earlier investigations[11-17] a large experimental excess over theory for IB from ^{32}P was reported, Berenyi and Varga[9-10] have made a detailed and critical experimental investigation of IB from ^{32}P and established a close correspondence between theory and experiment lending support to earlier investigations[8,18] in which only small deviations between theory and experiment were reported. Even in the investigation of Berenyi and Varga,[9,10] when the maximum possible errors were considered the reported extent of agreement between Coulomb corrected Knipp, Uhlenbeck, and Bloch (KUB) theory due to Nilsson and experiment was only within 15% in the energy region 60–1060 keV. In the present study, the IB from ^{32}P was measured again and the results confirm the findings of Berenyi and Varga.

EXPERIMENTAL DETAILS

The IB spectra were measured with a scintillation spectrometer consisting of a Harshaw cylindrical NaI(Tl) crystal (3.8 cm in diameter and 2.5 cm long) mounted on a Dumont 6292 photomultiplier. The pulses were amplified in a linear amplifier and then analyzed with a Nuclear Data (series 1100) multichannel analyzer system with facilities for storage, display, typing, and plotting of experimental spectra.

The β sources of ^{185}W and ^{32}P were obtained from the Bhabha Atomic Research Centre (BARC), Trombay, Bombay, India. The source ^{32}P was supplied in a carrier free solution containing about 20 mCi/ml. The ^{185}W source was supplied in the form of a high specific activity solution containing 10 mCi/ml. The above mentioned absolute activities were determined with an accuracy of better than 6% at BARC in a 4π counting geometry. Typical values for the amounts of total solid per millicurie were 0.2 mg for ^{32}P and 2 mg for ^{185}W. The solids in the active solutions were almost entirely compounds of fairly low atomic number and the fraction of heavy atoms was very small. Owing to the low intensity of the IB, a strong source would have been preferable, so that the counting rate would far exceed the background counting rate. This was, however, not possible because in thick sources external bremsstrahlung (EB) is created in the source itself. Only when the source is extremely thin and uniform is this interference small. The actual IB sources were prepared by evaporating their respective active solutions over circular areas of 0.5 cm diam on 50 μg/cm^2 polystyrene films with the help of dilute insulin solution. The films were supported on thin Perspex rings of inner diameter 5 cm and outer diameter 6 cm which were well outside the solid angle accepted by the detector. In the case of ^{32}P, three sources were prepared having absolute activities of 150, 305, and 470 μCi and having thicknesses of 50, 75, and 100 μg/cm^2, respectively. Four sources of ^{185}W were prepared which had absolute activities of 50, 75, 146, and 226 μCi with thicknesses of 95, 148, 299, and 385 μg/cm^2, respectively. For both isotopes, the EB production in the source material, due to its finite thickness, though small, was examined by measuring the γ spectrum from the prepared IB sources of different thicknesses. As the intensity in all the cases did not change appreciably it was concluded that source thickness did not affect the final results. The absolute activities of the prepared IB sources were determined using a well type plastic phosphor detector with an accuracy of ±6%. All prepared IB sources were tested for β impurity by examining the β spectrum with an anthracene crystal with a resolution of 20% for 626 keV conversion electrons. Also careful examination of the radiation from all the sources was undertaken with a Ge(Li) detector, with a resolution of 2.7 keV for ^{137}Ba γ rays, in order to detect possible peaks in the spectra due to impurities emitting nuclear γ rays. These tests indicated that no contamination was present.

The geometrical arrangement used in the present investigation is shown in Fig. 1. The source was kept 19 cm above the face of the detector and a Perspex β stopper was situated about halfway between the source and the detector to absorb all the β particles from the source. The crystal photomultiplier assembly was housed in a lead cylinder with an outer diameter of 27 cm and a wall thickness of 8 cm and was thus adequately shielded from external background. The undesirable fluorescent radiation from lead *K* x rays from the lead collimator and shield was eliminated by lining the inside of the collimator hole and the detector side of the collimator with aluminum. In order to reduce the EB interference and scattering effects from the air, the IB source was enclosed within a Perspex chamber (see Fig. 1) and the entire space between the source and the detector and the volume within the chamber were evacuated to about 1 Torr. Under these conditions the calculated EB from the Perspex chamber was less than 2%. X rays and γ rays from ^{141}Ce, ^{203}Hg, ^{133}Ba, ^{137}Cs, and ^{22}Na were used to calibrate the linear energy scale. The variation of energy calibration during the measurement of

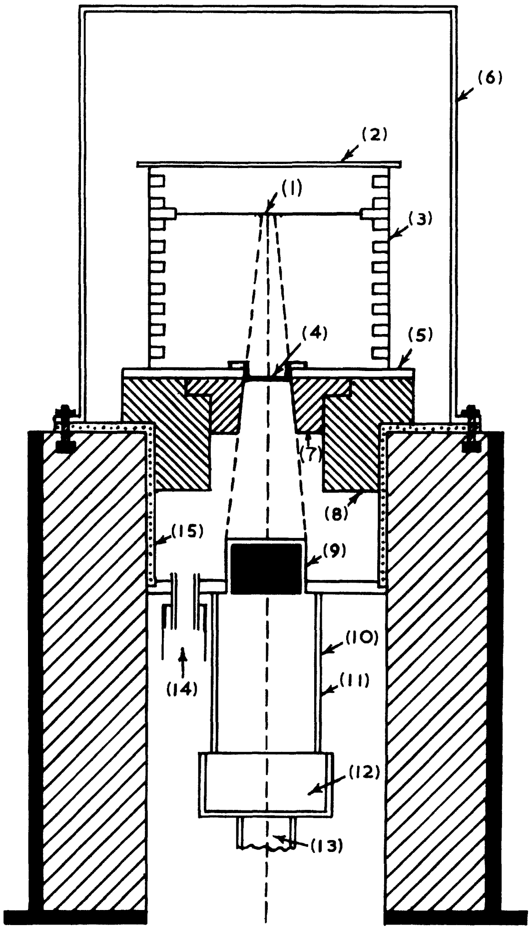

FIG. 1. Cross-sectional view of the geometrical setup. (1) Source, (2) Perspex ring, (3) Perspex rod, (4) β stopper, (5) Perspex disk, (6) Perspex chamber, (7) and (8) Lead collimator, inside surface being lined with aluminum, (9) sealed NaI(Tl) crystal, (10) black adhesive tape, (11) photomultiplier, (12) preamplifier and cathode follower, (13) to adjustable floor stands, (14) to vacuum pump, and (15) aluminum chamber.

each spectrum was less than 1.5%. The full width at half maximum of the 662 keV γ line of ^{137}Cs was 10.5%.

The weak sources and the relatively low intensity of the radiation, especially at high photon energies, resulted in long observation times. Actually, the multichannel scintillation spectrometer was continuously run for several days in order to obtain a single IB spectrum with counting statistics of 1.5% at the high energy end of the IB spectrum for each isotope. Under these conditions particular care was taken to obtain the required accuracy of the energy and channel width calibration. Calibration changes of the spectrometer were found to be less than 0.5% per day. Since constant room temperature is essential for the achievement of such stability, the whole apparatus was kept in an air conditioned room during the measurements.

The consistency between the various observed pulse height distributions resulting from different runs was found to be between 2–3 % for each isotope. During the experimental measurements of the IB pulse height distributions, sufficient collection times were used so that the number of counts above background, at the higher energy end of the spectrum, yielded a statistical error of 1.5%. For the sake of conveniently illustrating both the high energy and the low energy portions of the IB spectra in a single figure, the spectra were renormalized and represented as shown in Figs. 2 and 3.

CORRECTIONS

In order to obtain the true IB photon distributions, the measured pulse height distributions for both isotopes were corrected for background, energy resolution, iodine K-x-ray escape, Compton electron distribution, etc., following the method of Liden and Starfelt.[22] Corrections were also made for the geometrical and γ detection efficiency of the crystal, for backscattering from the photomultiplier glass window, from the crystal con-

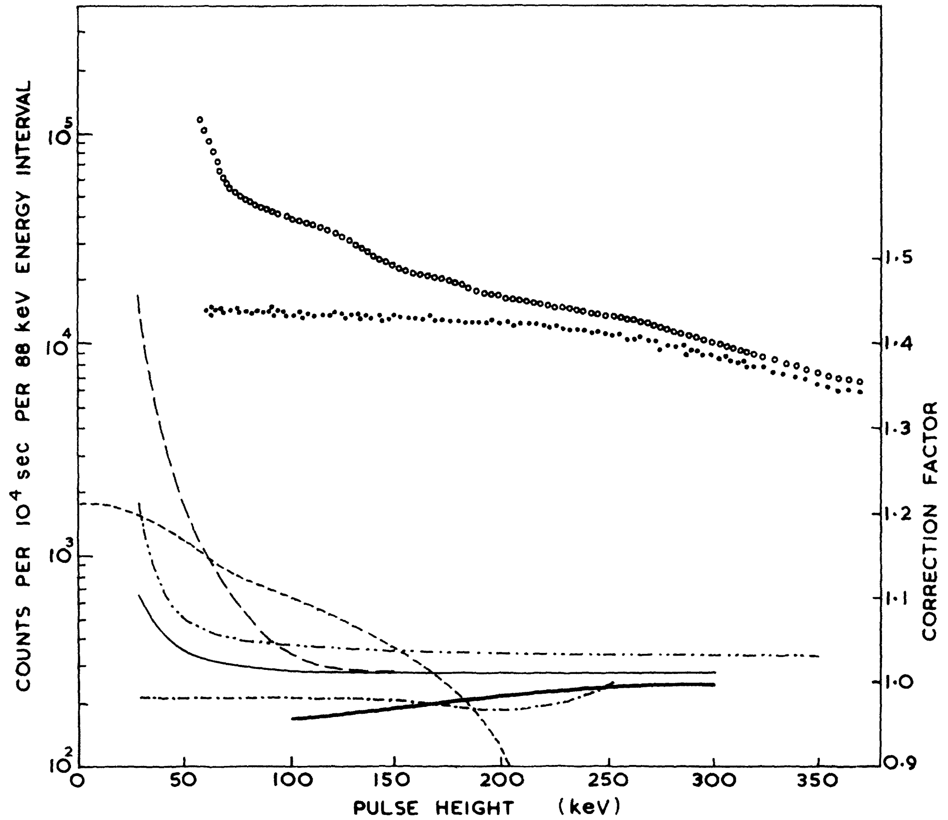

FIG. 2. Corrections to the measurement of internal bremsstrahlung spectrum of ^{185}W. ooo— experimentally measured pulse height distribution, ····— background spectrum, and - - - -— Compton electron distribution. Correction factors: — — — —correction factor for the iodine K-x-ray escape, -·-— correction factor for the resolving power, ——— correction factor for external breemsstrahlung in the Perspex β stopper, -··— correction factor for absorption in β absorber, and —— —correction factor for absorption in aluminum can of the NaI(Tl) crystal.

tainer, and also from the surrounding material used as shielding. Correction for the absorption of the radiation in the β stopper and in the aluminum can of the sodium iodide crystal and for the external bremsstrahlung produced within the source and the absorber was made in a manner similar to that of Narasimha Murty and Jnanananda.[23]

In effecting the K-x-ray correction, values of K-x-ray fractions calculated by Axel[24] for the case of good geometry were employed. Of the various corrections mentioned above, the correction due to the Compton electron distribution becomes important when there are photons of high energy present. In correcting for the Compton electron distribution, the shape of the Compton distribution for a given energy was approximated by a straight line. In order to test the validity of this straight line approximation, the complete pulse height spectra resulting from the monoenergetic γ-ray lines from ^{141}Ce (145 keV), ^{203}Hg (280 keV), ^{198}Au (412 keV), ^{137}Cs (662 keV), ^{54}Mn (840 keV), and ^{65}Zn (1165 keV) were recorded for the same geometry employed in measurement of IB spectra. For all cases, the experimentally measured Compton distributions were found not to deviate much from a straight line. The resulting error was also found to be within 3% which is well within the

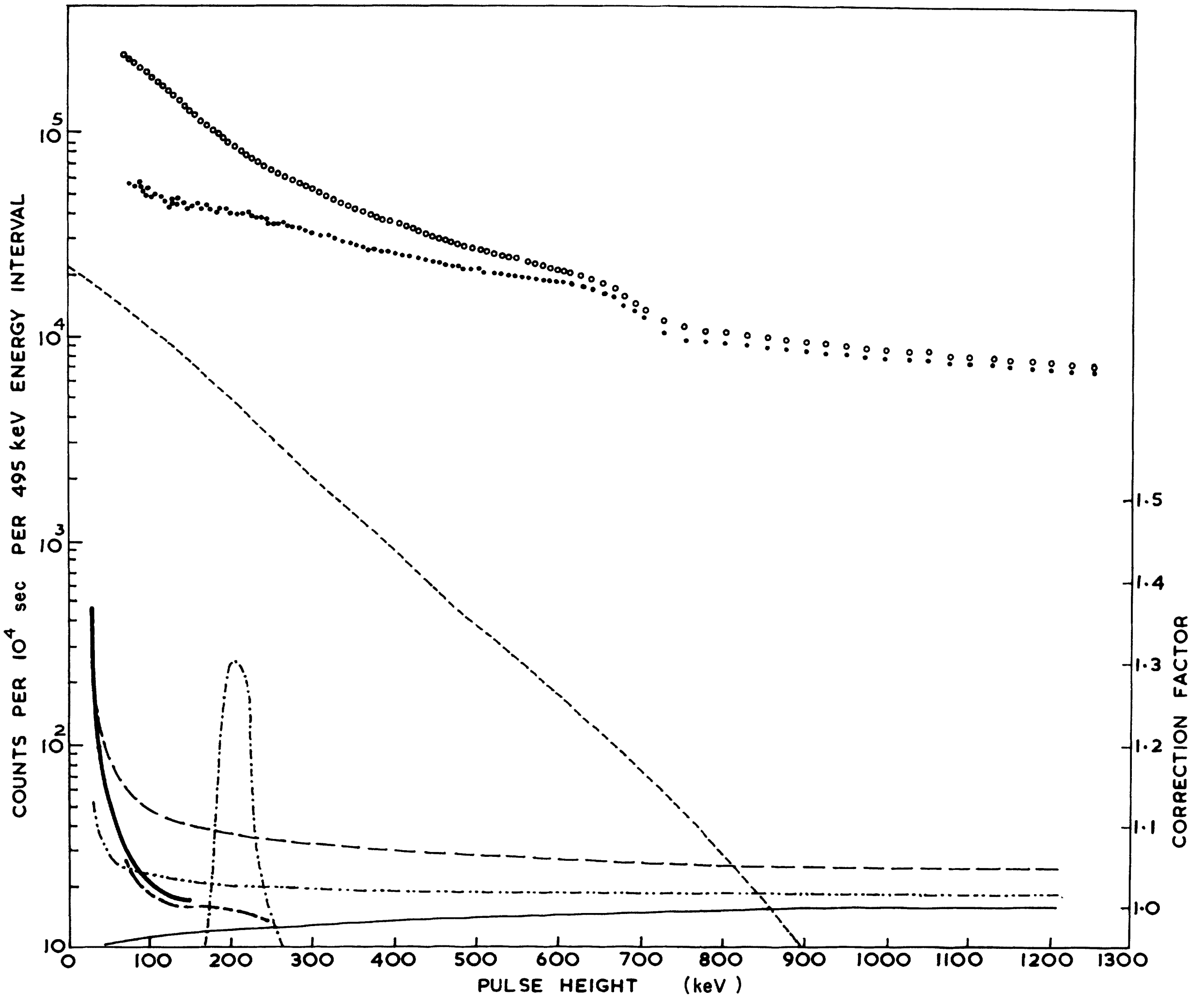

FIG. 3. Correction to the measurement of internal bremsstrahlung spectrum of ^{32}P. ooo— experimentally measured pulse height distribution, ··· —background spectrum, --- —Compton electron distribution, and -·- —backscattering distribution. Correction factors: —— —correction factor for the iodine K-x-ray escape, — - — —correction factor for the resolving power, —— —correction factor for external bremsstrahlung in the Perspex β stopper, --- —correction factor for absorption in β absorber, and -·· —correction factor for absorption in aluminum can of the NaI(Tl) crystal.

rms value of the compound error of the experiment at that energy.

In the determination of the correction for the geometrical and γ detection efficiencies, the peak-to-total ratios employed were determined experimentally by recording the complete pulse height spectra for the monoenergetic γ-ray lines mentioned above. In this context it may be remarked that still better values of the peak-to-total ratio can be obtained by the use of larger crystals, while the detection efficiency also improves.

In correcting for absorption in the Perspex β absorber and in the aluminum can of the NaI(Tl) crystal, the absorption coefficients given in Hubbel's tables[25] were used. The correction to the IB due to the scattered radiation from the Perspex β absorber and from the hole of the lead collimator was calculated by the Klein-Nishina formula, assuming single scattering, and it was found to be negligible. The contribution of external bremsstrahlung from the Perspex β stopper to the IB spectra was arrived at by extrapolation of the experimental measurements of EB to $Z = 0$ for various energies for the elements Al, Cu, and Sn. The resulting correction factors are separately given for both isotopes in Figs. 2 and 3. As can be seen from the figures, this correction gradually decreases from low energies to zero at high energies and is observed not to exceed 4% even at low energies. At the very low energies included in this investigation the ratio of the intensity of EB from the Perspex β stopper to that of the IB was calculated under the assumption that the EB is emitted isotropically.

It is possible for the sum pulses resulting from the finite resolving time of the electronics to distort the measured distribution of IB at the high energy end where the number of real counts is very low. An estimate of this distortion was made as follows: Let the number of true counts in the distribution of energies E_1 and E_2 be, respectively, n_1 and n_2 and let the resolving time of the electronics be τ. It follows that the number of spurious pulses that will be added to the distribution at an energy (E_1+E_2) is $2\tau n_1 n_2$. To calculate the sum pulse contribution at a given energy one must add such contributions from all possible combinations of energies. This procedure fixes an upper limit to the sum pulse contributions. The actual contribution will be somewhat less than the above limit because of the finite rise time of the pulses. By employing this procedure, with a value of 2 μsec for τ, this source of error was found to be less than 1.5%.

The experimentally recorded pulse height distributions of IB from ^{185}W and ^{32}P are shown in Figs. 2 and 3 along with the various corrections mentioned earlier. The fully corrected IB distribution for each isotope was obtained from the observed distribution first by subtracting the corresponding background and the calculated Compton and backscattered distributions and then by multiplying it by the total correction factor which includes factors shown in Figs. 2 and 3 and also the geometrical and γ-detection efficiency factor.

ERRORS

Finally, we discuss the sources and estimates of the errors involved in the measurement of the IB distribution as well as in the calculations of the various corrections. The errors due to energy calibration and channel width were observed to be very small—not more than 2%. The statistical error is less than or equal to 1.5% throughout the energy range for the two IB spectra recorded in the present investigation. The error in the correction for the EB from the Perspex β stopper is mainly due to the uncertainty caused by the assumption of isotropic emission of the EB and it is found to be within 2%. The uncertainty in the calculated values of the total K-x-ray escape factors introduces corresponding error in the correction for the K-x-ray escape, and this error is very small ranging from 0.1–1 % for the NaI(Tl) crystal employed in the present studies in the energy range from 30 to 140 keV. Also the error involved in the calculation of the correction for the finite energy resolution is very small, not exceeding 1% throughout the energy region of interest. The error involved in applying the backscattering correction which exists only for the case of IB pulse height distributions from ^{32}P is of comparatively little importance as this correction and its error are small.

The inaccuracy in calculating the Compton electron distribution is mostly due to the assumption that the Compton distribution is constant with energy. This source of error is estimated to be less than 4% throughout the energy region of interest, the estimate being based on a comparison between the straight line approximation for the Compton distributions corresponding to different monoenergetic γ photons and their experimentally determined Compton distributions.

Of all the various types of possible errors, the error in the calculation of the crystal detection efficiency is the largest one, and it arises from the uncertainty in the values of the absorption coefficients of sodium iodide as well as from the uncertainty in the values of the experimentally determined peak-to-total ratios. The sodium iodide absorption coefficients are correct to within 1–2 % and the peak-to-total ratios are

TABLE I. Estimated errors in the *IB* spectra (in percent). The total error does not include the inaccuracy of the absolute calibration of the source.

Energy (keV)	Energy calibration	Resolving power +K-x-ray escape	Compton continuum	Crystal efficiency	Counting statistics	EB from Perspex stopper	Total rms
				^{32}P			
30	1.5	2.0	0.5	1	0.5	2.0	3.40
50	1.0	2.0	0.5	1	0.5	1.5	2.96
100	1.0	1.0	0.5	2	0.5	1.0	2.74
200	1.0	0.5	0.5	2	1.0	1.0	2.74
350	1.0	0.5	1.0	3	1.0	1.0	3.64
500	0.5	0.5	2.0	4	1.1	1.0	4.80
700	0.5	0.3	3.0	5	1.3	1.0	6.08
1000	0.5	0.3	2.0	6	1.5	1.0	6.60
1200	0.5	0.2	2.0	7	1.5	1.0	7.12
				^{185}W			
30	1.5	2.0	0.5	1	0.5	2.0	3.40
50	1.0	2.0	0.5	1	0.5	1.5	2.96
100	0.5	1.0	0.5	2	1.0	1.0	2.74
250	1.0	0.5	0.5	2	1.3	1.0	2.86
350	0.5	0.5	1.0	3	1.5	1.0	3.69

reliable to within 5%. Together these two factors result in an over-all error in detection efficiency of not more than 7%.

The inaccuracy in the determination of the total activity of the source does not influence the shape of the spectral distribution but affects only the photon intensity, hence it is concluded, that by excluding this error and taking into account the remaining errors, the present results for ^{185}W are correct to within 5% and for ^{32}P to within 9%. These are the rms values of the percentage errors considered separately for the two cases under consideration. The total errors of 5 and 9% actually correspond to the uncertainty in the IB at high energies, and as the energy decreases the error also decreases. In addition the errors mentioned above are given separately for both isotopes in Table I for which the errors in the determination of the total activities of the sources were not included. In this table, errors in the corrections for backscattering (<1%) and scattering in the collimator (<1%) as well as absorption in the aluminum can of the NaI crystal and Perspex β stopper (1–2 %) are not shown though they were included in the total rms error reported.

RESULTS AND DISCUSSION

Allowed and the nonunique first forbidden transitions are found to yield theoretical IB spectra which differ from each other very slightly both with regard to intensity and shape and irrespective of the type of interaction. For purposes of comparison with experiment, theoretical IB distributions were calculated in the present investigation according to the similar theories developed independently by Knipp and Uhlenbeck[26] and by Bloch[27] which is usually referred to as KUB theory. Coulomb corrected distributions were also calculated according to the theory of Lewis and Ford,[28] since it is developed for both allowed and forbidden β decays. However, in the case of ^{185}W the Lewis and Ford distribution was found to be insufficient to bring theory into agreement with experiment. In an attempt to obtain improved agreement between theory and experiment, the Coulomb corrected distribution was also calculated in the Nilsson approximation[29] although it is valid only for allowed β decay.

The Coulomb corrected and uncorrected theoretical IB distributions were calculated in the same way as indicated in Sec. IV of the earlier paper of Narasimha Murty and Jnanananda.[23] In those calculations, the experimentally determined β spectra[30, 31] of ^{185}W and ^{32}P were substituted for the β decay probability $P(W_e)$ individually. The calculations of the IB theoretical distributions and the evaluation of the various corrections were all made with an IBM 1130 computer.

For purposes of comparison between theory and experiment, the theoretical distributions were calculated in units of photons per MeV per β disintegration. The final experimental IB photon distributions were also obtained first as number of photons per MeV by dividing the corrected IB pulse height distributions by the channel width ΔK in units of mc^2 and then by multiplying by 1 MeV in units of mc^2. In the case of the ^{185}W IB spectrum, the absolute intensity was obtained by dividing the experimental data by the β strength of the source and afterwards it was directly compared as such (number of photons per 1 MeV per β disintegration) with the corresponding theoretical distributions. In the case of IB from ^{32}P most of the early investigations established good agreement between the KUB theory and experiment at low photon energies with regard to absolute yields as well as spectral shape. Therefore, it was felt that a study of the shape of the IB spectrum alone would be sufficient. Hence the experimental IB distribution in photons per MeV was normalized so as to match the KUB theoretical distributions at 100 keV where the excellent agreement between theory and experiment had been reported earlier. The present experimental results are shown, along with their corresponding theoretical distributions, in Figs. 4 and 5 in the photon energy ranges from 60 to 370 keV for ^{185}W and 30 to 1250 keV for ^{32}P. The small vertical line over each experimental point in both the Figs. 4 and 5 is a measure of the total rms value of the error involved in the experimental measurement at that energy. For the experimental points for which no limits of error are given, it is implied that the limits there lie within the symbols. The discussion of the IB results for each isotope is given below.

^{185}W

The decay of ^{185}W is classified as nonunique, first forbidden with an end-point energy of 429 keV and half-life of approximately 75 days. From the Fig. 4 it can be seen that the experimental IB distribution is in agreement, within the limits of the experimental accuracy, with the KUB theory[26, 27] in the energy region from 78 to 200 keV, whereas at energies greater than 200 keVand less than 78 keV the experimental points are far above even the highest Coulomb corrected theoretical distribution due to Nilsson.[29] In this case the contribution to the IB from the influence of the nuclear Coulomb field is large because of the large value of Z as can be seen from the Fig. 4; yet at high as well as at very low energies, it could not bring theory into agreement with experiment. Moreover, in those energy regions we have determined that the difference between theory and experiment is too large to be caused by systematic errors. From this we conclude that in this case the Coulomb correction to the theory is insufficient

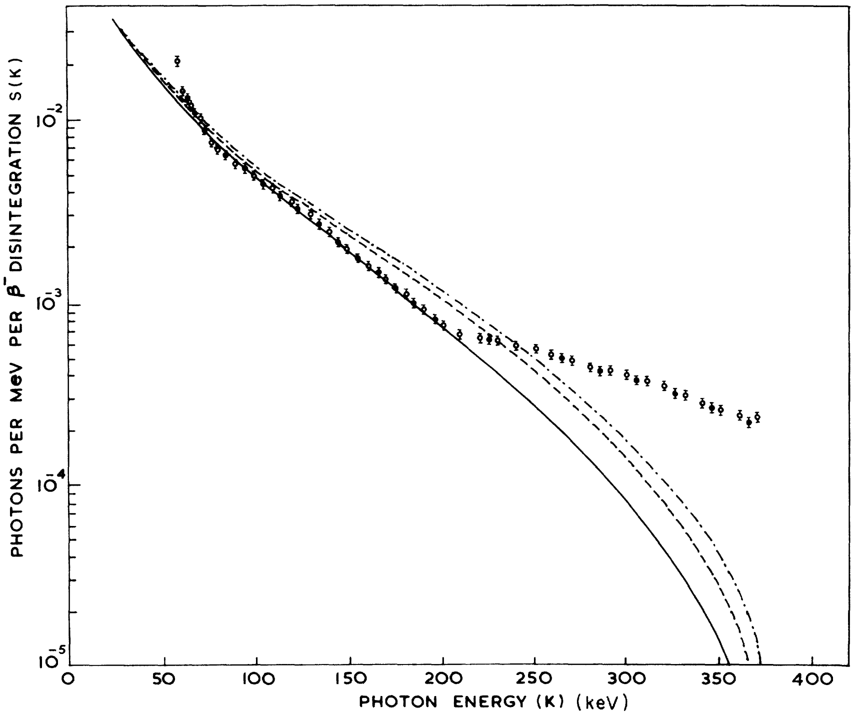

FIG. 4. ^{185}W internal bremsstrahlung intensity spectrum. Experimental data: ooo— source strength 75 μCi and ··· — source strength 146 μCi. Theoretical curves: —— —KUB distribution, ---— Lewis and Ford distribution, and -·-— Nilsson distribution.

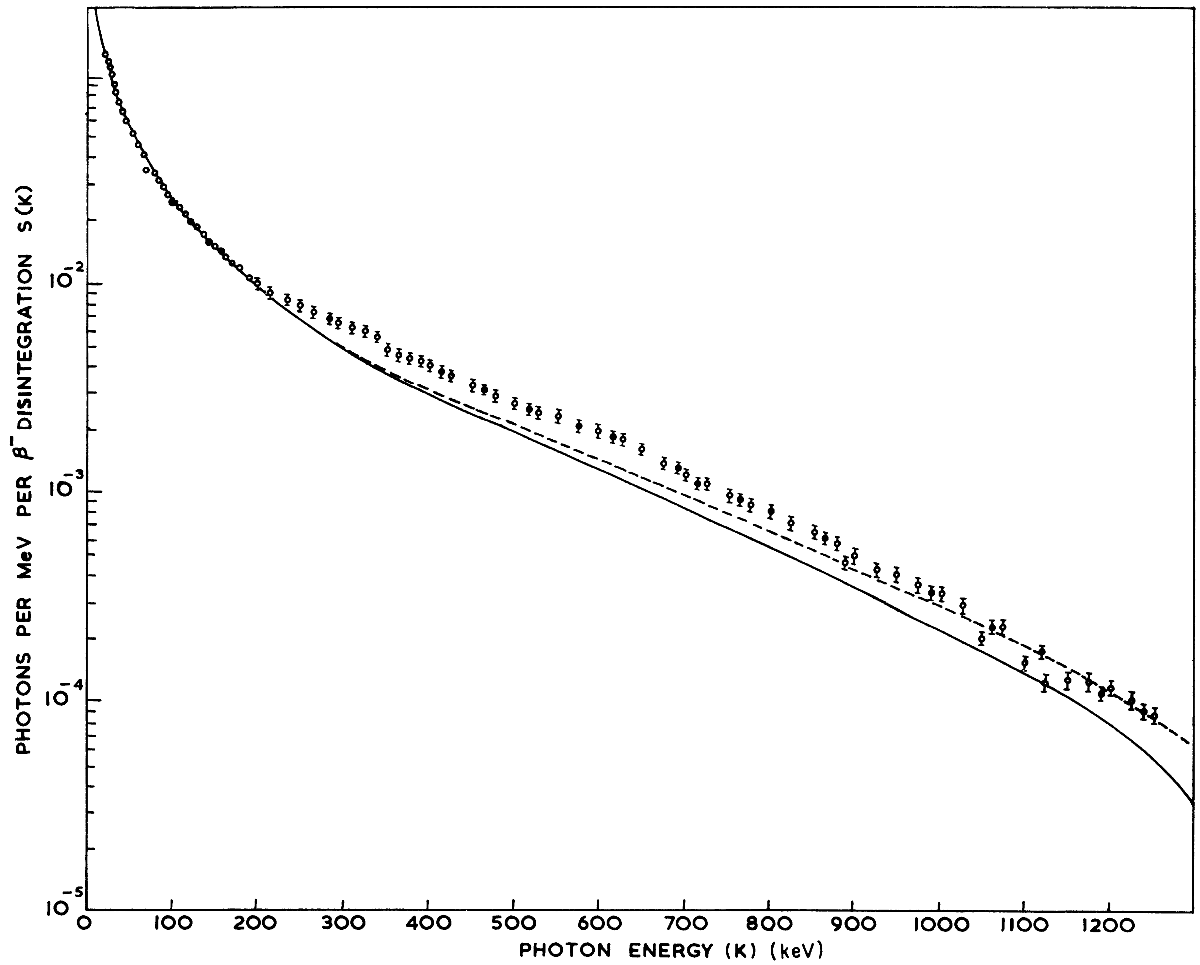

FIG. 5. ^{32}P internal bremsstrahlung intensity spectrum. Experimental data: ooo and ··· different source strengths ranging from 100 to 500 μCi. Theoretical curves: —— —KUB distribution and ---— Lewis and Ford distribution.

to explain the discrepancy. According to the theories of Felsner[32] and also of Vinh-Mau,[33] the nuclear charge enhances the yield of IB even to a larger extent than in the Nilsson theory. Therefore, an improved agreement with the shape of the experimental spectrum at those energies mentioned above might be expected from these theories.

Also it is appropriate to mention the possibility of the contribution to the IB arising from detour transitions[34-36] in the case of ^{185}W, since this effect can be significant in forbidden β decays. In a number of cases of forbidden β decay, this effect was calculated in the previous investigations[8,36] which resulted in improved agreement between

TABLE II. Comparison between the present experiment and different theoretical distributions.

Energy (keV)	Number of photons × 10^5 per MeV per β disintegration KUB	Lewis and Ford	Nilsson	Detour	Present experiment
300	7.85	14.40	17.10	24.11	39.9
320	4.19	8.17	10.51	15.61	34.8
340	2.11	3.95	5.51	9.90	28.7
360	0.73	1.67	2.57	3.51	23.5

theory and experiment. Therefore, for this case also calculations were made of the effect of the detour transitions at various photon energies according to the theory of Ford and Martin.[36] In the present calculations, however, an approximation was made that the nuclear matrix elements for the direct and detour transitions have equal amplitudes. These theoretical values of the contribution to IB due to detour transitions are given in Table II. For comparison, the KUB theoretical values[26,27] as well as those of Lewis and Ford[28] and of Nilsson are also furnished along with the present experimental values in the same table. From Table II, it is obvious that although the detour corrected theoretical values lie much higher than the Nilsson values, they do not completely account for the experimental IB results at the higher energies. We conclude that according to our treatment of the detour transitions, their effects do not account completely for the discrepancy between theory and experiment.

Since we could not see any likely cause of spurious effects in our experiment, we must conclude that the observed excess is real. We find it very difficult to offer a satisfactory explanation for this observed effect except by pointing out that in this case as well as in other cases of earlier investigations,[8,21] the theories are inadequate at high photon energies to account for the large experimental observed excess. For instance, in the investigation of Beattie and Byrne[21] we note that near the end-point energy the intensity of IB is greater than that predicted by Nilsson theory by as much as a factor greater than 8 for ^{210}Bi and even larger for ^{204}Tl. In the present case for ^{185}W the experimental excess over the Nilsson theory is a factor of 3.3 at 320 keV and a factor of 9.5 at 360 keV, while the experimental excess over the detour theory at these energies is by factors 2.2 and 6.7, respectively.

We conclude that in order to explain the generally observed behavior of the disagreement between experiment and theory concerning IB, namely, a positive deviation of experiment from theory, which increases with increasing photon energy, it is desirable and worthwhile to consider the possibility of developing new theories which include effects which were ignored previously.

^{32}P

^{32}P is found to have an allowed spectral shape, an end-point energy of 1.71 MeV, and a half-life of approximately 14 days. The Coulomb correction in this case is small and, as can be seen from Fig. 5, is about 15% at 1 MeV, and decreases rapidly at lower energies. Also it can be noticed that in the energy region from 30 to 200 keV the experimental points coincide with the KUB theory[26,27] and in the energy region from 200 to 900 keV the experimental results exceed both the KUB theory and the Coulomb corrected Lewis and Ford theory.[28] The excess over Lewis and Ford theory is on the order of 15% on an average. Even if the maximum uncertainty is taken into account in that energy region, the deviation of experiment from the Lewis and Ford theory is not more than 18%. On the other hand, in the high energy region above 900 keV, the experimental distribution coincides with Lewis and Ford distribution. In this case it may be mentioned that the Nilsson theoretical distribution[29] was found not to differ much from the Lewis and Ford theoretical distribution. Since the present experimental results are seen to agree with the Lewis and Ford theory there was no need to include the Nilsson theoretical distribution in Fig. 5.

The general trend of the present experimental results in this case compare favorably with those of earlier investigations in which a close correspondence between the KUB and Nilsson theories and experiment was reported. Of the various single counter measurements of IB from ^{32}P carried out previously, we consider the one due to Berenyi and Varga[9,10] very reliable. The present results indicate almost the same agreement between experiment and the Coulomb corrected KUB theory as that reported by Berenyi and Varga in the energy region of 200–900 keV, while below 200 keV both the present results and those of Berenyi and Varga reveal complete agreement between experiment and KUB theory. Therefore, we conclude that the present IB results from ^{32}P do not reveal anything new but do serve as a check on the present apparatus and procedure employed in the study of IB from ^{185}W which has not been investigated previously.

B. Persson, in *Proceedings of the International Conference on Electron Capture and Higher-Order Processes in Nuclear Decay, Debrecen, Hungary, 15–18 July 1968* (Eötvos Lóránd Physical Society, Budapest, Hungary, 1968), Vol. 2, p. 142.

[2] G. J. Sizoo, C. Eijkman, and P. Groen, Physica 6, 1057 (1939).

[3] L. Madansky and F. Rassatti, Phys. Rev. 83, 187 (1951).

[4] T. B. Novey, Phys. Rev. 89, 672 (1953).

[5] P. Bolgiano, L. Madansky, and F. Rassetti, Phys. Rev. 89, 679 (1953).

[6] A. Michalowicz, J. Phys. Rad. 15, 156 (1954).

[7] M. Goodrich and W. B. Payne, Phys. Rev. 94, 405 (1954).

[8] M. A. Hakeem and M. Goodrich, Nucl. Phys. 31, 322 (1962).

[9] D. Berenyi and D. Varga, Nucl. Phys. A138, 685 (1969).

[10] D. Berenyi and D. Varga, Acta Phys. 29, 1 (1970).

[11] K. Liden and N. Starfelt, Phys. Rev. 97, 419 (1955).

[12] K. A. Korotkov and A. M. Chernikov, Izv. Akad. Nauk SSSR Ser. Fiz. 24, 899 (1960) [Bull. Acad. Sci. USSR, Phys. Ser. 24, 899 (1960)].

[13] K. A. Korotkov and A. P. Shumeryko, Izv. Akad. Nauk SSSR Ser. Fiz. 29, 2243 (1965) [Bull. Acad. Sci. USSR, Phys. Ser. 29, 2083 (1965)].

[14] K. A. Korotkov and V. I. Kryshkin, Izv. Akad. Nauk SSSR Ser. Fiz. 29, 2247 (1965) [Bull. Acad. Sci. USSR, Phys. Ser. 29, 2086 (1965)].

[15] W. Kreisch, W. Lampert, and G. Loos, Nucl. Phys. A107, 601 (1968).

[16] G. Loos, W. Kreisch, W. Lampert, and H. J. Trebst, in Proceedings of the International Conference on Electron Capture and Higher-Order Processes in Nuclear Decay (See Ref. 1), p. 182.

[17] H. Langevin-Joliot, Ann. Phys. (Paris) 2, 16 (1957).

[18] B. Persson and S. A. E. Johansson, Nucl. Phys. 12, 432 (1959).

[19] B. Persson, Nucl. Phys. 18, 131 (1960).

[20] J. E. Thun, W. D. Hamilton, K. Siegbahn, and K. E. Eriksson, Ark. Fys. 12, 565 (1962).

[21] R. J. D. Beattie and J. Byrne, Nucl. Phys. A161, 650 (1971).

[22] K. Liden and N. Starfelt, Ark. Fys. 7, 427 (1954).

[23] K. Narasimha Murty and S. Jnanananda, Proc. Phys. Soc. 90, 109 (1967).

[24] P. Axel, Rev. Sci. Instrum. 25, 391 (1954).

[25] J. H. Hubbel, National Bureau of Standards Report No. 29 NSRDS-NBS, 1969 (unpublished).

[26] J. K. Knipp and G. E. Uhlenbeck, Physica 3, 424 (1936).

[27] F. Bloch, Phys. Rev. 50, 272 (1936).

[28] R. R. Lewis and G. W. Ford, Phys. Rev. 107, 756 (1957).

[29] S. B. Nilsson, Ark. Fys. 10, 457 (1956).

[30] P. Mallikharjuna Rao, Ph. D. thesis, Andhra University, 1974 (unpublished).

[31] E. N. Jensen, R. T. Nichols, J. Clement, and A. Pohm, Phys. Rev. 85, 112 (1952).

[32] G. Felsner, Z. Phys. 174, 43 (1963).

[33] R. Vinh-Mau, Nuovo Cimento 19, 609 (1961).

[34] C. Longmire, Phys. Rev. 75, 15 (1949).

[35] J. Horowitz, J. Phys. Rad. 13, 429 (1952).

[36] G. W. Ford and C. F. Martin, Nucl. Phys. A134, 457 (1969).