Beta Decay of Naturally Radioactive In^{115}†

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(Received January 23, 1961)

A liquid scintillator loaded with indium has been used to study the fourth-forbidden beta decay of In^{115}. Specific activity measurements yield a half-life of $(6.9\pm1.5)\times10^{14}$ years. A crude beta spectrum was obtained. Linear extrapolation of the Fermi-Kurie plot gives an end-point energy of 625 ± 70 kev.

INTRODUCTION

FROM the rules of nuclear stability, one of the adjacent isobars of In^{115} and Sn^{115} is expected to be unstable to beta decay. Geochemical evidence[1] and experiments with Geiger counters[2,3] searching for the characteristic x radiation of indium were negative and showed the half-life of Sn^{115} undergoing orbital electron capture to be greater than about 10^{12} yr.

Martell and Libby[4] used a screen wall counter in some careful measurements on samples of indium obtained from several different geographical locations. Comparisons with the results obtained using isotopically enriched samples showed the activity to be due to the beta decay of In^{115}. From absorption measurements they determined the beta end-point energy to be 0.63 ± 0.03 Mev. No accompanying gamma radiation was observed. Their results gave a half-life of $6\pm2\times10^{14}$ years for In^{115}. Cohen,[5] using Geiger counters with indium cathodes, detected a beta activity which corresponded to a half-life of $\sim10^{14}$ yr for In^{115}.

The spins and parities of In^{115} and Sn^{115} are known[6] to be $9/2+$ and $\frac{1}{2}-$, respectively. These values indicate a fourth-order forbidden beta transition and are consistent with the *ft* value of 2×10^{22} obtained by Martell and Libby. This is the only known example of a fourth-forbidden beta decay.

Measurements by Bell *et al.*[7] on the decay of the 4.4-hr isomeric state of In^{115} lead to the conclusion that the energy of the natural beta decay of In^{115} to Sn^{115} should be equal to 490 kev, which is in disagreement with the 630 kev obtained by Martell and Libby.

The present measurements, using a scintillation detector, were undertaken to obtain information on the shape of the beta spectrum and as a check on the energy discrepancy mentioned above.

APPARATUS

A liquid scintillator[8] containing 2.56% indium trihexanoic acid (1.0% indium metal, by weight) was used to detect the In^{115} betas. 63.9 grams of the liquid scintillator solution were contained in a 2-in. diam×2-in. high glass cell of low potassium content.[9] A similar cell containing 65 g of a liquid scintillator loaded with cadmium was used to determine the background. This comparison detector contained 0.98% cadmium metal by weight. The two cells were covered with a special reflector coating by the supplier. A third unloaded liquid scintillator was used as a check on the background measurements.

The cell to be counted was mounted on a low-noise photomultiplier (EMI9578S) in a vertical position. Pulses were taken from across a 47-kohm anode load resistor directly to a type A-61 linear amplifier and counted by a 256-channel pulse-height analyzer. Another detector consisting of a 5-in. diam×6-in high plastic scintillator with a $2\frac{5}{8}$-in. diam×$4\frac{1}{8}$-in. deep well was mounted over the liquid scintillator cell and connected in anticoincidence. A thin layer of MgO and a 0.03-in. thick copper sheet surrounded the plastic scintillator which was coupled to a 5-in. diam photomultiplier. This anticoincidence arrangement was effective in reducing the Compton background from an external 662-kev gamma source by approximately 25%.

Shielding on the sides was provided by several concentric sections of iron pipe to give a total thickness of $2\frac{1}{4}$ in. iron. The pipes were surrounded by 5 in. of lead on the side. The shielding on the top consisted of $3\frac{3}{4}$ in. iron and 4 in. lead and on the bottom 1 in. iron plus 4 in. lead.

COUNTING AND RESULTS

Runs made with the three different liquid scintillators, in turn, were 30–40 hr in duration. The total

† Supported in part by the U. S. Air Force under a contract monitored by Air Force Office of Scientific Research of the Air Research and Development Command.

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[2] E. Zingg, Helv. Phys. Acta **13**, 219 (1940).
[3] L. I. Rusinov and J. M. Igelnitsky, Compt. rend. acad. sci. U.R.S.S. **53**, 631 (1946).
[4] E. A. Martell and W. F. Libby, Phys. Rev. **80**, 977 (1950).
[5] S. G. Cohen, Nature **167**, 779 (1951).
[6] "Nuclear level schemes," National Research Council, NRC-60-3-105.
[7] P. R. Bell, B. H. Ketelle, and J. M. Cassidy, Phys. Rev. **76**, 574 (1949).
[8] Obtained from Nuclear Enterprises, Ltd., Winnipeg, Manitoba, Canada. The percentages quoted are those provided by the supplier.
[9] Obtained from Corning Glass Works, Corning, New York.

counting time for each scintillator was approximately 120 hr. System gain checks were made every 8–10 hr using the Compton edge produced by an external 662-kev gamma source. These were made *in situ* with the top shielding removed. The performance of the anti-coincidence arrangement was checked at the same time. The zero level of the analyzer was checked at 30–40 hr intervals. Gain and zero level were maintained to within approximately 2%. Final energy calibrations were made by comparing the *in situ* calibrations with the positions of the Compton edges of several different external gamma sources determined for the three scintillators. Individual runs agreed with each other within statistics. The absolute counting of the pulse-height analyzer was checked by counting the alpha activity of Sm^{147} using a similar cell containing a samarium-loaded liquid scintillator. This samarium activity had been previously measured using a single-channel analyzer.

As was expected, the metal-organic compounds in the loaded scintillators reduced their scintillation efficiencies. The relative pulse amplitudes of the Cd- and In-loaded cells were approximately 70% and 47%, respectively, of those produced by the unloaded scintillator. Accompanying these reductions in scintillation efficiencies was a deterioration in the resolutions as determined from the half-widths at half maxima of the Compton edges from the 662-kev gamma source, e.g., these resolutions (fractional half-width at half maximum) were 28%, 23%, and 17% for the In-loaded, Cd-loaded, and unloaded scintillators.

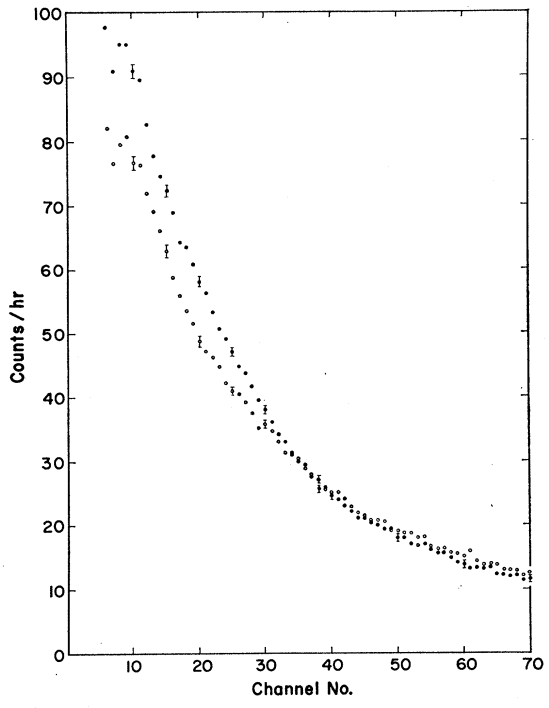

FIG. 1. Differential spectra. The closed circles represent the data obtained using the In-loaded scintillator, and the open circles show the background obtained with the Cd-loaded comparison scintillator. No correction has been made for the slightly different amounts of solution present in the two cells.

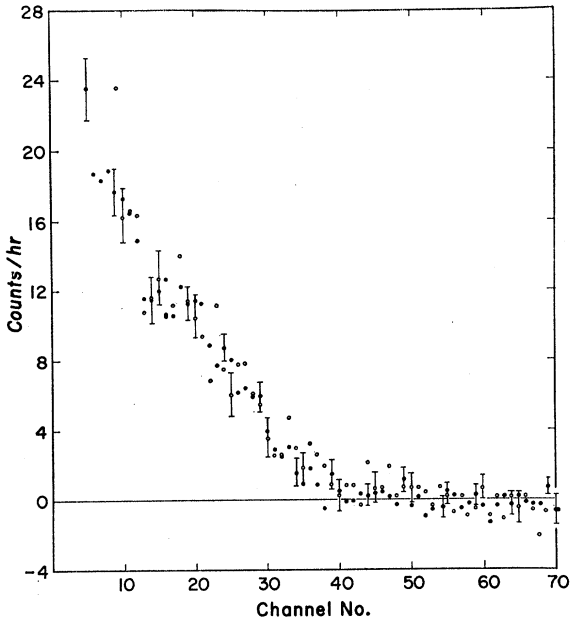

FIG. 2. Beta spectrum of In^{115}. The closed circles show the difference between In-loaded cell and the unloaded comparison cell. The open circles show the difference between the In-loaded cell and the Cd-loaded comparison cell. The data have been normalized to compensate for slight differences in total scintillation efficiencies of the three cells.

Figure 1 shows the spectra obtained with the In-loaded and Cd-loaded scintillators. The data are not considered reliable below channel 10 because of electronic noise and analyzer nonlinearities. The spectrum obtained with the unloaded scintillator was indistinguishable, within statistics, from that obtained with the Cd-loaded detector. This indicates that the effects of the resolution differences of the different detectors on the determination of the smoothly varying background are small enough to be neglected. This assumption was checked by deteriorating the resolution of the Cd-loaded cell to approximately that of the In-loaded cell and taking additional runs with the Cd-loaded scintillator. No difference was distinguishable in the two cadmium runs.

The raw data showed the spectrum obtained with the Cd-loaded scintillator crossing that obtained with the In-loaded in the region between channels 34–37 and lying a small distance above at higher energies. The difference can be accounted for by the slightly different amounts of scintillation material present in the two cells. A normalization factor (0.957) based on the total counts in the interval between channels 45 and 60 was used to adjust the spectrum obtained with the Cd-loaded cell. This adjustment has not been made in the data shown in Fig. 1.

Figure 2 shows the differences between the spectrum

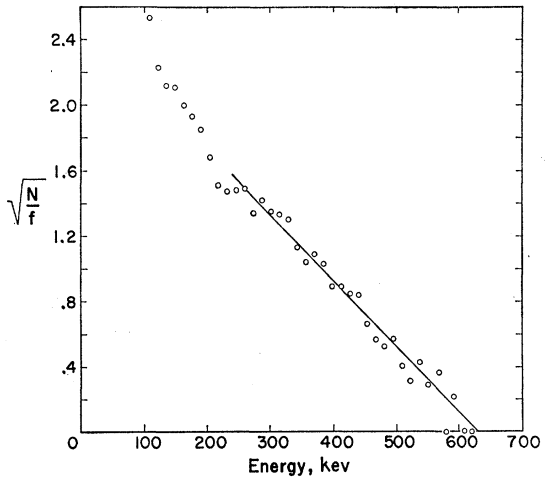

FIG. 3. Fermi-Kurie plot of the fourth order forbidden beta decay of In^{115}.

obtained with the In-loaded cell and the two reference spectra. The end point of the beta spectrum is in channel 40±3 which corresponds to 600±70 kev. The error quoted on the maximum beta energy includes the estimated uncertainties in the rather crude energy calibration made using the Compton edges of several different gamma-ray spectra. The energy calibration was carried out in this way because the response of the cells to gamma rays was not such as to show photopeaks and it was not feasible to introduce calibration sources emitting internal conversion electrons directly into the scintillators.

Figure 3 shows the Fermi-Kurie plot of the fourth-forbidden beta decay of In^{115}. Corrections for finite resolution[10] have not been made. These were uncertain because of the large scatter in the original data, and rough estimates of their magnitude showed them to be comparable to the statistical error. The corrections for escape of the electrons from the surfaces of the scintillator are small and have also been neglected. A linear approximation to the Fermi-Kurie plot is shown. Extrapolation of this straight line yields an end-point energy of 625±70 kev. This is in excellent agreement with maximum energy of 630 kev obtained by Martell and Libby.[4]

The end-point energy obtained is in disagreement with the energy difference of 490 kev between the ground states of In^{115} and Sn^{115} computed from the data of Bell *et al.*[7] This suggests that either there are unexpectedly large errors in the beta-energy measurements reported here and by Martell and Libby, or that the decay of the 4.4-hr isomeric In^{115} is to an excited state of Sn^{115} which has been thus far undetected. A re-examination of the 4.4-hr activity is underway in this laboratory.

No attempt has been made to further analyze the Fermi-Kurie plot because of the large uncertainties in the data and because of the questionable value of such an analysis.

The integral spectrum obtained by integrating the data presented in Fig. 2 is shown in Fig. 4. Extrapolation to zero energy gives a total activity of 360±75 counts/hr or a specific activity of 560±120 counts/hr per gram of indium metal. This extrapolation is made from ~160 kev and includes ~40% of the total count rate. In view of the general shapes of highly forbidden beta spectra, i.e., the maxima of the energy spectra occurring at very low energies, it is felt that such a large extrapolation does not appreciably increase the error in the final result. The uncertainty quoted includes an estimate of the accuracy of the quantitative analysis of the total indium content provided by Nuclear Enterprises Ltd.[11]

Using the relative isotopic abundance of 0.958 of In^{115}, one obtains a half-life of $(6.9\pm1.5)\times10^{14}$ yr. This is in reasonably good agreement with the result of Martell and Libby.[4] This result assumes that all the activity observed is attributable to In^{115}. That this is reasonable is based on the following: (1) The highest

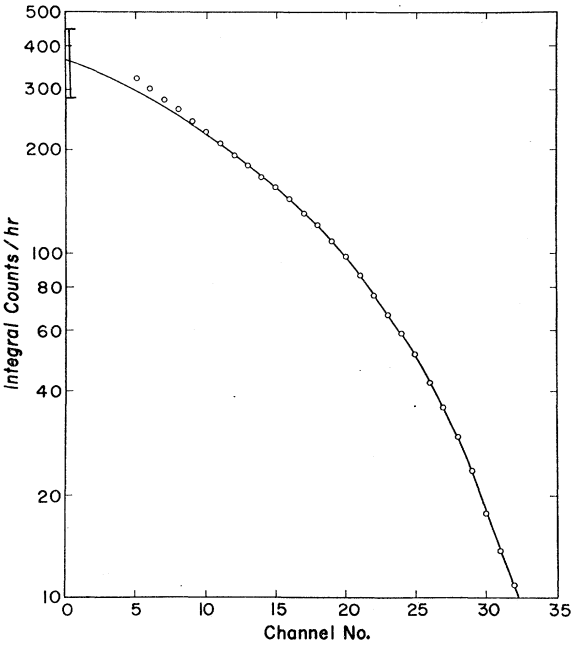

FIG. 4. In^{115} integral spectrum obtained from the data in Fig. 2. Extrapolation to zero energy yields a total activity of 360±75 counts/hr corresponding to a specific activity of 560±120 counts/hr. per gram of indium metal and a half-life for In^{115} of $(6.9\pm1.5)\times10^{14}$ years.

[10] J. P. Palmer and L. J. Laslett, Ames Laboratory Rept. AECU-1220 (1951).

[11] W. R. Allison (private communication).

purity indium available was used in the liquid scintillator;[11] (2) the spectrum obtained does not have the structure associated with a possible alpha-emitter contaminant such as thorium, nor is it similar to that obtained with gamma rays; (3) the activity has been observed for a period of $1\frac{1}{2}$ yr and has not changed in this time.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Dr. W. R. Allison and Dr. B. L. Funt of Nuclear Enterprises, Ltd., for preparing the metal-loaded liquid scintillators. The assistance of W. N. Schreiner and D. A. Gollnick in the recording and analysis of the data is gratefully acknowledged.

PHYSICAL REVIEW VOLUME 122, NUMBER 5 JUNE 1, 1961

Coherent Scattering of 1.17-Mev and 1.33-Mev Gamma Rays through Small Angles*

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(Received April 29, 1960; revised manuscript received January 3, 1961)

The dependence of the differential cross section for the coherent scattering of 1.17-Mev and 1.33-Mev gamma rays on atomic number was investigated. An empirical procedure, which makes an absolute determination of the cross sections unnecessary, was used to estimate the Compton scattering cross sections. The latter were subtracted from the measured cross sections in order to obtain the relative coherent scattering cross sections, which were found to vary as Z^n. Our average value for n is 3.07 ± 0.18.

The angular distribution of the total (coherent and Compton) scattering cross section was also investigated in the case of copper and lead between 2.43° and 5.79°. Our results are compared with the existing theoretical predictions and with the results of the earlier experiments, wherever the latter are available.

I. INTRODUCTION

NUCLEAR resonance scattering, Delbrück scattering by the nuclear Coulomb field, Thomson scattering by the nuclear charge, and Rayleigh scattering by the bound electrons in an atom represent different processes involving the coherent scattering of energetic gamma rays by atoms. Of these processes, resonance scattering plays an important role only under very special conditions.[1] Since Delbrück scattering[2] does not follow from the classical linear field equations of Maxwell, a great deal of attention has been focused recently on its experimental verification. Experiments[3] on the scattering of bremsstrahlung photons of 87-Mev mean energy through angles of a few milliradians appear to have established the existence of Delbrück scattering. Detailed calculations[4] of Delbrück scattering cross sections are extremely difficult and have not yet been made. Previous experiments,[5–9] though somewhat conflicting among themselves, have shown that Delbrück scattering is so small for large scattering angles at 1.17 and 1.33 Mev as to be almost undetectable. The corresponding situation for small scattering angles is not clear at the moment. Since the rest energy of a nucleus is much greater than the energy of gamma rays used in our experiments, scattering by the nuclear charge as a whole can be evaluated by the classical Thomson expression. For angles less than six degrees and for gamma-ray energies in the neighborhood of 1 Mev, nuclear Thomson scattering cross sections are expected to be smaller than 0.7% of the Rayleigh scattering cross sections. Therefore, scattering experiments in the small-angle region are very useful in the investigation of the Rayleigh scattering process. Similar experiments have been previously carried out at 0.411 Mev,[10] at 0.325 and 0.660 Mev,[11] and at 1.17 and 1.33 Mev.[12]

Calculations of Rayleigh scattering cross sections in the energy region of interest were first carried out by Franz,[13] with the assumption of the Fermi-Thomas

* Work supported in part by a grant from the Research Corporation.

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‡ Part of this work was submitted by G. M. H. to Honours College, Wesleyan University, in partial fulfillment of the requirements for the Bachelor of Arts degree with Distinction. Present address: Graduate School, Harvard University, Cambridge, Massachusetts.

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