The Third Forbidden Beta Spectrum of Rubidium-87†

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The use of thin-lens beta spectrometers has been extended to the measurement of an isotope of extremely low specific activity, rubidium 87. The Rb^{87} beta spectrum is third forbidden and not "unique." The spectrum gave a linear Kurie plot when the third forbidden tensor (or vector) correction factor was applied. The extrapolated value $E_{max}=275$ kev agreed well with the results of recent investigations.

An extension of a recent measurement of the Rb^{87} half-life was carried out with an enriched sample of Rb^{87}, and a value $T_{\frac{1}{2}}=6.2\pm0.3\times10^{10}$ years was obtained.

I. INTRODUCTION

THE radioactive decay of rubidium-87 into strontium-87 has been studied by many investigators. The long half-life of the decay and the low energy of the emitted beta particle combine to make accurate measurements of the decay constants extremely difficult. Although absorption measurements indicated that no gamma rays are present in the decay,[1] some investigations[2–6] seemed to point to a complex beta spectrum, containing one or more conversion electrons. Other experiments[1,7,8] indicated that the beta decay is directly to the ground state of Sr^{87}. In a previously reported paper by the present authors,[9] a coincidence measurement was described which showed that the presence of any conversion electrons in the decay is highly unlikely.

Measurements of the half-life of the decay that have been made[1,7,8,10] must be carefully evaluated. Often large corrections were necessary for the solid angle subtended, self-absorption in the source, back-scattering from the support, and assumptions concerning the decay scheme. Corrections of this nature can lead to a considerable uncertainty in the final result.[11,12] In the paper mentioned above,[9] the present authors reported a half-life measurement that depended on only one correction factor, the extrapolation to zero source-plus-backing thickness. A value for the specific activity of 478 counts per gram of natural RbCl per second was obtained. Subsequent to this report, an electromagnetically-enriched sample of RbCl was obtained from the Carbon and Carbide Chemicals Division at Oak Ridge, Tennessee. This sample contained 89.62 percent Rb^{87} as compared with 27.85 percent Rb^{87} in natural rubidium.[13] Three very thin enriched RbCl sources were prepared and counted in the manner previously described. The data for the enriched sources yield a value of the half-life, $T_{\frac{1}{2}}=6.2\pm0.3\times10^{10}$ years. The thinnest source-plus-backing thickness was 0.05 mg/cm², which corresponds to a zero-thickness extrapolation from about 5 kev to zero.

Measurements of the maximum energy of the beta spectrum range from 130 kev to 560 kev.[5,14–16] The two most recent spectra reported, those of Curran[7] and Lewis,[8] both give maximum energies of about 275 kev, a result also confirmed by Bell.[17] Curran used a RbCl source placed on the cathode of a proportional counter. Lewis used a rubidium iodide crystal mounted on the end of a photomultiplier tube.

II. PRELIMINARY MEASUREMENTS WITH A THIN-LENS SPECTROMETER

In an attempt to determine if a magnetic measurement of the rubidium-87 beta spectrum would be feasible, a conventional thin-lens beta spectrometer was used to test the effect of large-area sources. On the basis of the results obtained, a special thin-lens spectrometer 16 inches in diameter and 42 inches in length was constructed. Sources and counters in a variety of sizes were investigated. With a source and counter each 4 inches in diameter, an optimum resolution of 10 percent was obtained, using the Cs^{137} conversion line for the measurement. In order to minimize the background counting rate, the final arrangement chosen was a source 4 inches in diameter and a counter 2 inches in diameter.

For the sake of beam intensity, the spectrometer baffles were placed to give a resolution of 14 percent. The effect of this rather poor resolution on the shape of the beta spectrum can be readily calculated. To a good approximation, the shape of a conversion line can

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1 S. Eklund, Arkiv Mat. Astron. Fysik **A33**, No. 14 (1946).
2 G. Hoffman, Z. Physik **25**, 177 (1924).
3 W. Mühlhoff, Ann. Physik **7**, 205 (1930).
4 G. Orban, Akad. Wiss. Wien, 2a, **140**, 121 (1930).
5 Z. Ollano, Nuovo cimento **18**, 11 (1941).
6 O. Haxel and F. G. Houtermans, Z. Physik **124**, 705 (1948).
7 Curran, Dixon, and Wilson, Phys. Rev. **84**, 151 (1951).
8 G. M. Lewis, Phil. Mag. **43**, 1070 (1952).
9 M. H. MacGregor and M. L. Wiedenbeck, Phys. Rev. **86**, 420 (1952).
10 Haxel, Houtermans, and Kemmerich, Phys. Rev. **74**, 1886 (1948).
11 Bähnisch, Huster, and Walcher, Naturwiss. **39**, 16, 379 (1952).
12 C. Charpak and F. Suzer, Compt. rend. **233**, 1356 (1951).
13 A. O. Nier, Phys. Rev. **79**, 450 (1950).
14 W. F. Libby and D. D. Lee, Phys. Rev. **55**, 245 (1939).
15 A. K. Saha, Proc. Natl. Inst. Sci. India **12**, 159 (1946).
16 T. Fazzini and S. Franchotti, Nuovo cimento **5**, 311 (1948).
17 Bell, Cassidy, and Davis, *Nuclear Data*, National Bureau of Standards Circular 499, Supplement 1 (U. S. Government Printing Office, Washington, D. C., 1951), p. 20.

be represented by an isosceles triangle. The ratio of the half-width of the triangle to the momentum of the line is defined as the resolution W. If we let $K(p,p')$ represent the shape of the conversion line, where p' is the momentum of the conversion electrons and p is the momentum corresponding to the current flowing through the spectrometer coil, the equation for the observed spectrum $n(p)$ in terms of the true spectrum $N(p)$ is:

$$n(p)=\int_0^\infty K(p,p')N(p')dp'.$$

Since $K(p,p')$ is a function only of the ratio of p to p', a Fourier expansion is feasible. The equation for the true spectrum in terms of the observed spectrum is then

$$N(p)\simeq\frac{n(p)}{p}-\frac{W^2}{12}\left(\frac{n(p)}{p}+4\frac{dn(p)}{dp}+\frac{d^2n(p)}{dp^2}\right).$$

For $W=0.14$, this correction amounts to less than 2 percent over most of the spectrum.

The spectrometer was calibrated with the 623.8-kev conversion line from Cs^{137}. As a check on the operation of the instrument, the S^{35} beta spectrum was run. With the source mounted on a thin Zapon film and with a counter window of 0.25-mil Mylar (0.6 mg/cm^2), the Kurie plot was linear down to about 70 kev. When the S^{35} source was sandwiched between two RbCl films having a combined thickness of 0.44 mg/cm^2, this simulated thick source gave a S^{35} Kurie plot that began to tail up at about 110 kev. (The RbCl, of course, contributed a negligible number of electrons.) The ratio of these two Kurie plots was used to apply a low-energy correction to the data obtained with a "thin" RbCl source (0.44 mg/cm^2), as described in the next section. The end-point energy of the S^{35} Kurie plot was 166 kev, which gave a good check on the calibration of the spectrometer.[18]

III. MEASUREMENT OF THE RUBIDIUM BETA SPECTRUM

In order to measure the rubidium spectrum, two enriched RbCl sources were prepared, each 4 inches in diameter. The RbCl was deposited on the backing by the process of sublimation from a hot crucible in a vacuum. This method insures microscopic uniformity. In order to obtain macroscopic uniformity, each source was put on in a series of four carefully-spaced evaporations. The "thin" source had a thickness of 0.44 mg/cm^2 and was deposited on an aluminized Zapon backing (0.05 mg/cm^2). The "thick" source had a thickness of 1.6 mg/cm^2 and was deposited on an aluminized Mylar backing (0.6 mg/cm^2).

Since the specific activity of RbCl is so low, the

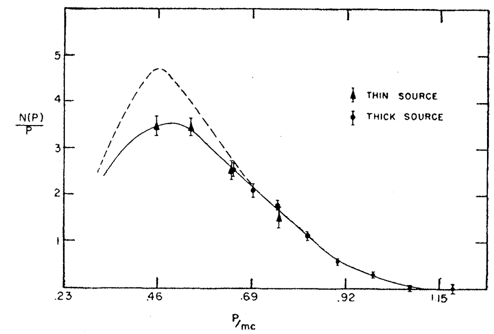

FIG. 1. Rubidium-87 momentum spectrum. The dotted line represents the spectrum before correcting for source thickness.

problem of reducing the background counting rate was extremely important. The spectrometer cell counter was made of copper and had a minimum volume consistent with good counter characteristics—2 inches in diameter and ½ inch in length. An anticoincidence counter was placed immediately beneath the spectrometer counter to eliminate cosmic ray counts. (The spectrometer was mounted vertically, with the source at the top.) The counter assembly and the inside of the spectrometer at the counter end were shielded with one inch of copper inside of two inches of lead. With external quench circuits on each counter, the spectrometer operation was stable enough so that reproducible results could be obtained.

The rubidium-87 beta spectrum that was measured is shown in Fig. 1. Each error flag represents an 84 percent probability that the point lies within the limits indicated. The correction for finite resolution has been applied, and the source-thickness correction derived from the S^{35} measurements has also been made. This spectrum agrees well with the spectrum obtained by Lewis[8] down to about 70 kev, at which point the spectrometer counter window absorption becomes important.

IV. ANALYSIS OF THE BETA SPECTRUM

The "allowed" Kurie plot of the Rb^{87} beta spectrum is nonlinear, as shown in Fig. 2. The spin change of

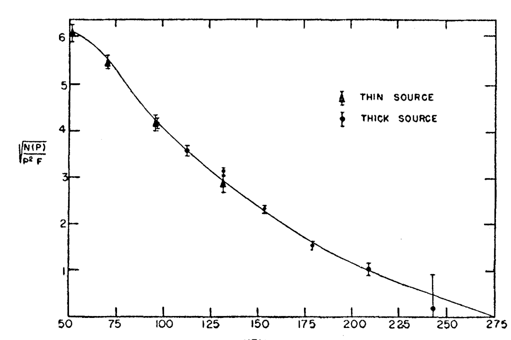

FIG. 2. Allowed Kurie plot of the rubidium-87 spectrum.

[18] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

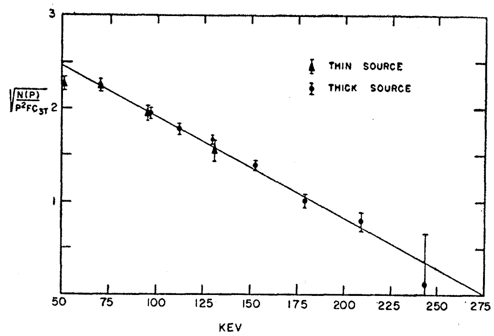

FIG. 3. Corrected Kurie plot of the rubidium-87 spectrum.

the nucleus is 3,[19,20] and the shell model predicts a parity change.[21] When the third forbidden tensor correction term is applied, the Kurie plot becomes linear, at least insofar as can be determined by the statistics (Fig. 3), and it indicates an upper energy limit of 275 kev, in good agreement with recent experiments.[7,8,17]

In the calculation of the third-forbidden correction factor, C_{3T} (Fig. 4), the expressions derived by Greuling[22] were evaluated with the assistance of the tables for L_v, M_v, N_v, P_v, Q_v, R_v computed by Rose *et al.*[23] In the terminology of Tomozawa, Umezawa, and Nakamura,[24]

$$C_{3T}=\left|\frac{Q_3(\beta\boldsymbol{\sigma}\times\mathbf{r},\mathbf{r})}{3!}\right|^2(f-2g\rho+\rho^2h),$$

where

$$\rho=Q_3(\beta\boldsymbol{\alpha},\mathbf{r})/Q_3(\beta\boldsymbol{\sigma}\times\mathbf{r},\mathbf{r}).$$

The values for f, g, and h published by Tomozawa *et al.*[24] are not correct,[25] and consequently the value $\rho=4.2$, obtained empirically, is also incorrect. Yamada[26] gives a theoretical value of $\rho=2.37$. This value does give the linear Kurie plot shown in Fig. 3. Since the cancellation of terms of nearly equal size is involved, C_{3T} is a very sensitive function of ρ.

It is interesting to note that in all the known cases of second and third forbidden beta spectra of the "nonunique" type,[27] the tensor (or vector) correction factor is sufficient to linearize the Kurie plot. At the present time it is difficult to draw conclusions as to the relative magnitudes of the scalar and tensor interactions for Rb^{87}.

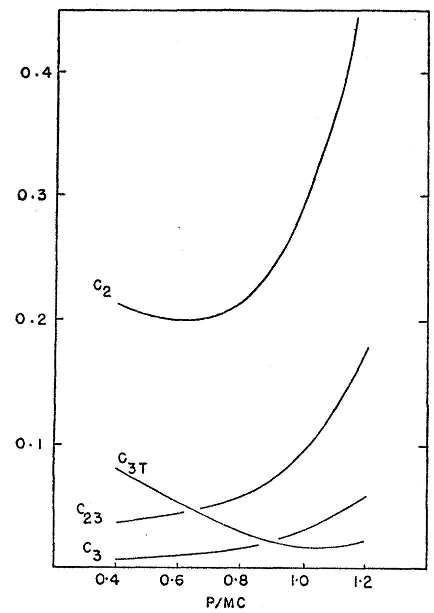

FIG. 4. Correction factor C_{3T} using $\rho=2.37$.

[19] S. Millman and M. Fox, Phys. Rev. **50**, 220 (1936).
[20] M. Heyden and H. Kopfermann, Z. Physik **108**, 232 (1938).
[21] P. F. A. Klinkenborg, Revs. Modern Phys. **24**, 63 (1952).
[22] E. Greuling, Phys. Rev. **61**, 568 (1942).
[23] Rose, Perry, and Dismuke, Oak Ridge National Laboratory Report ORNL-1459 (unpublished).
[24] Tomozawa, Umezawa, and Nakamura, Phys. Rev. **86**, 791 (1952).
[25] S. Nakamura (private communication).
[26] M. Yamada, Progr. Theoret. Phys. Japan **9**, 268 (1953).
[27] E. J. Konopinski and L. M. Langer, Ann. Rev. Nuclear Sci. **2**, 301 (1953).