Beta Spectrum of C^{14}

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The beta spectrum from thin sources of C^{14} was measured in a double thin-lens β-ray spectrometer; the momentum spectrum and the Fermi plot are presented. The Fermi plot for a source of approximately 15 $\mu g/cm^2$ is a straight line down to about 30 kev; the experiment therefore indicates an allowed shape for the beta spectrum of C^{14}. Existing experimental evidence to the contrary, that is, for a forbidden spectrum, is discussed and compared with the results of the present experiment.

IN recent years the puzzling fact of the extremely long half-life of C^{14} ($\log_{10} ft \sim 9$) led to several theoretical attempts to interpret the problem in terms of nuclear structure[1,2] rather than from the standpoint of beta-decay theory. On the basis of the long half-life the $C^{14} \rightarrow N^{14}$ transition should be forbidden; on the basis of beta-decay theory the well established change in spin from $0 \rightarrow 1$, taken in conjunction with the recent experimental proof by Bromley and Goldman[3] of no change in parity, leads one to expect an allowed transition in accordance with Gamow-Teller selection rules.

Today the interpretations mentioned above[1,2] are no longer tenable; the experiment by Bromley refutes Gerjuoy's hypothesis of a parity change, that of Van de Graaff *et al.*[4] makes the assumption of pure ^1S (C^{14}) and ^3D (N^{14}) states implausible. Experimentally, on the other hand, the answer to the question of forbidden *versus* allowed transition is not clear-cut either, with some investigators claiming an allowed[5] and some a forbidden[6] shape for the C^{14} beta spectrum.

Under these circumstances, and inasmuch as the question is one of considerable theoretical interest, a re-examination of the shape of the C^{14} spectrum seemed indicated, with special attention to those factors which might affect the curvature of the Fermi plot, e.g., instrumental distortion, uniformity and thickness of the source, window thickness, etc. In the present experiment a double thin-lens spectrometer was used with a resolution of 1.5 percent. The detector in the spectrometer was a GM type counter provided with a Nylon window of ~ 30 $\mu g/cm^2$. The source material was $NaHCO_3$, converted chemically from $BaCO_3$ of high specific activity, obtained from the Isotope Division at Oak Ridge. Thin uniform sources were formed on Tygon films of about 10-$\mu g/cm^2$ thickness. To insure proper position, size, and uniformity of the source, the part of the backing foil on which the source was to be placed was wetted with an aqueous solution of insulin prior to the addition of the radioactive material. Thin narrow strips of aluminum (0.17 mg/cm^2) were placed near the end of the deposit to minimize electrostatic effects caused by charging up of the source. For drying, the sources were placed in a desiccator filled with nitrogen in order to avoid any loss of activity due to exchange with CO_2 in the atmosphere. Autoradiographs of sources made in this manner showed a uniform distribution over the whole area covered by the radioactive material. The Tygon backing used in the comparison of sources of different thickness was made from the same film, thus ensuring that any diversity in the results could be relegated to the difference in the sources, but would be independent of the backscattering in the backing foils.

The momentum distribution of the electrons from C^{14} obtained for sources of approximately 15 $\mu g/cm^2$ (A) and 60 $\mu g/cm^2$ (B) are shown in Fig. 1, the Fermi plot of the beta spectra of sources A and B in Fig. 2. Both figures indicate the distortion of the spectrum of the thicker source due to the excess of low-energy electrons. The Fermi plot is a straight line for both sources; the spectrum of the thin source remains straight to ~ 30 kev, where the effect of window

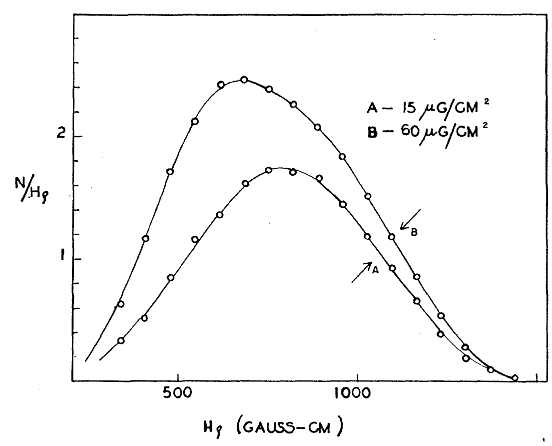

FIG. 1. Momentum distribution of the electrons of C^{14}. The relative number of counts per unit momentum interval is plotted against the momentum in units of gauss-cm.

[1] E. Gerjuoy, Phys. Rev. **81**, 62 (1951).
[2] E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949).
[3] D. A. Bromley and L. M. Goldman, Phys. Rev. **86**, 790 (1051).
[4] Van de Graaff, Sperduto, Buechner, and Enge, Phys. Rev. **86**, 966 (1952).
[5] L. E. Glendenin and A. K. Solomon, Phys. Rev. **74**, 700 (1948); L. Feldman and C. S. Wu, Phys. Rev. **75**, 1286 (1949); C. S. Wu and A. Schwarzschild, Phys. Rev. **91**, 483 (1953).
[6] J. L. Berggren and R. K. Osborne, Phys. Rev. **74**, 1240 (1948); Cook, Langer, and Price, Phys. Rev. **74**, 548 (1949); Angus, Cockraft, and Curran, Phil. Mag. **40**, 522 (1949); S. D. Warshaw, Phys. Rev. **80**, 111 (1950).

absorption in the counter becomes noticeable. The thick source deviates from linearity at ~45 kev, where the experimental points rise above the straight line, indicating thick source distortion. A still thicker source of ~90 $\mu g/cm^2$ (not shown in the diagram) remained straight to ~60 kev, where it also deviated upward. The extrapolated end point for all sources occurred at 155.0±1 kev, in good agreement with the results of other investigators.[5,6]

The results of this experiment, therefore, yield an allowed shape for the beta spectrum of C^{14}. Allowed distributions can be obtained under certain conditions for forbidden transitions; however, whatever the explanation of the long half-life, the other characteristics of the $C^{14}\rightarrow N^{14}$ decay ($\Delta I=1$, no) put it into the class of allowed transitions in accordance with Gamow-Teller selection rules.

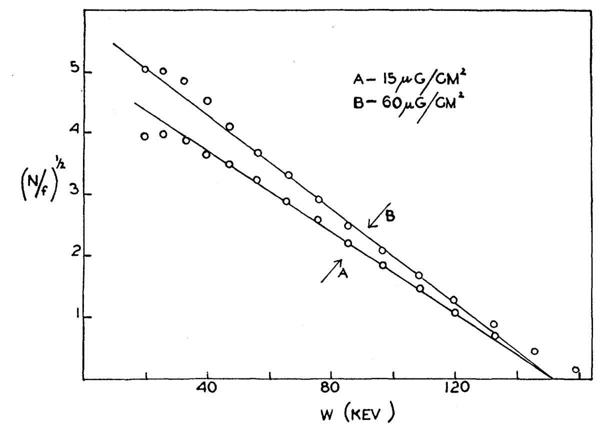

FIG. 2. Fermi plot of C^{14}.

In the light of the present experiment it seems of interest to re-evaluate the experimental evidence for a forbidden spectrum. The spectrum observed by Angus *et al.* gave a straight Kurie plot between 50 and 130 kev. Near the endpoint the authors found a slight excess of particles; below 50 kev the experimental points fell below the straight line, indicating a rapid decrease in intensity toward zero at a few kev. However, it may be argued that the departure from linearity is not too significant inasmuch as the spectrum remains straight over the major part of the energy range; and that near the endpoint the small number of pulses may give rise to an error in the counting rate. The deficiency of low-energy electrons is more difficult to understand since the source material was introduced directly into the counter; yet it also may be traceable to some instrumental distortion. As for the other experiments yielding a forbidden shape of the beta spectrum, Bergeren and Osborne found that for an average source thickness of ~100 $\mu g/cm^2$ the departure from a linear Kurie plot was ~3 percent. According to Cook *et al.*, the slight curvature of the Fermi plot was independent of source thickness for sources ranging from 130–970 $\mu g/cm^2$. On the other hand, Warshaw found that a thick source (180 $\mu g/cm^2$) gave a straight line plot above 80 kev, while a thin source (60 $\mu g/cm^2$) was convex to the energy axis within the same energy range; the departure from linearity was of the order of 3 percent. All of the experiments described above had in common the use of thicker sources than were studied in the present experiment. Moreover, "average" source thickness may become meaningless if nonuniform deposits produce local variations in grain density resulting in thick source distortions. A systematic departure from linearity of the order of 3 percent could not have escaped detection in our experiment.