the above Hartree points to within two percent. The diamagnetic corrections listed in Table IV agree closely with other presentations of the same information.[36, 57]

Very small corrections to these results may still be necessary because of the addition of paramagnetic salts to our samples[58] and have likewise been omitted in Table I. Systematic errors of various instrumental kinds have been examined and found to be negligible.[4]

The authors wish to take this opportunity to express their appreciation for the stimulation and guidance of a year's association with Professor Felix Bloch whose contributions to this work are too manifold to detail. We wish also to thank Dr. F. Alder for his assistance during the period of the measurements upon the isotopes of indium and molybdenum.

[57] Properties of Atomic Nuclei, Publication BNL 26 (T-10), Brookhaven National Laboratories, October 1, 1949.
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The Disintegration of Rb^{88}*

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The radioactive disintegration of Rb^{88} (17.8 min) has been investigated in a magnetic lens spectrometer. Three beta-ray groups are observed having maximum energies of 5.13 ± 0.03, 3.29 ± 0.10, and 2.04 ± 0.15 Mev, with intensities of 66, 19, and 15 percent, respectively. The 5.13 Mev group has a forbidden shape indicating a spin change of 2 units and a parity change. Gamma-rays are found with energies of 0.90, 1.86, and 2.8 Mev. A unique decay scheme is presented giving levels in Sr^{88} at 1.86 and 2.8 Mev. These levels are substantiated by a previous investigation of the disintegration of Y^{88} to Sr^{88}. Spins and parities of Rb^{88}, Sr^{88}, and Y^{88} are discussed in the light of the one particle shell model.

I. INTRODUCTION

The radioactivity of Rb^{88} has been studied by various investigators. Glasoe and Steigman[1] have identified a 17.8-min. beta-activity with Rb^{88} and have measured the beta-ray end point as 4.6 Mev by absorption in aluminum. G. L. Weil,[2] by cloud chamber measurements, observed two beta-ray groups with energies of 5.0 and 2.5 Mev. The period was measured as 17.5 min. Thus $\log ft$ for the high energy group was determined as $\sim$7.0, suggesting a forbidden transition.

The gamma-rays of the product nucleus Sr^{88} have been investigated by several groups.[3–7] There is general agreement on gamma-ray energies of approximately 0.908, 1.86, and 2.8 Mev. These investigators have used sources of Y^{88}, which decays to Sr^{88} by positron emission and K electron capture with a half-life of 108 days.

A further investigation of the Rb^{88} beta-radiation employing higher resolution seemed desirable, since the previous work indicated complexity of the spectrum and the possibility of a unique shape.

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[1] G. N. Glasoe and J. Steigman, Phys. Rev. **58**, 1 (1940).
[2] G. L. Weil, Phys. Rev. **62**, 229 (1942).
[3] G. S. Goldhaber, Phys. Rev. **59**, 937 (1941).
[4] J. R. Richardson, Phys. Rev. **60**, 188 (1941).
[5] Downing, Deutsch, and Roberts, Phys. Rev. **60**, 470 (1941).
[6] G. R. Gamertsfelder, Phys. Rev. **66**, 288 (1944).
[7] W. C. Peacock and J. W. Jones, Plut. Proj. Rep. CNL-14, February, 1948, unpublished.

II. EXPERIMENTAL METHOD

The investigation of the beta- and gamma-radiation from Rb^{88} (17.8 min) was performed with the aid of a large magnetic lens spectrometer.[8] An end-window Geiger tube with a 3.6-mg/cm² mica window and 0.5-inch diameter aperture was employed as a detector. This aperture, together with sources of similar diameter, yielded 6-percent resolution.

Two circular beta-ray sources were prepared from finely powdered Rb_2SO_4. The first was 26 mg/cm² on a 0.0002-inch Al backing and covered with a thin Zapon film. The second source was 30 mg/cm² on a backing of 0.7-mg/cm² nylon, which had been coated with Aquadag to maintain it at ground potential. A thin Zapon cover was again employed.

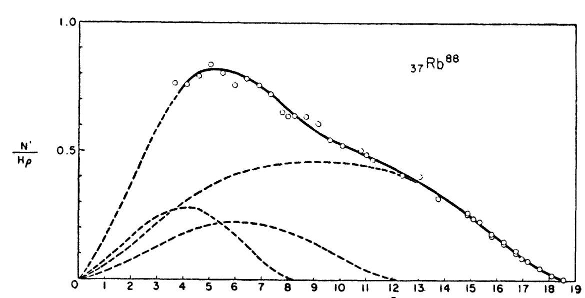

FIG. 1. Beta-spectra of Rb^{88}. The partial spectra are determined from the Fermi plot analysis.

[8] L. M. Langer, Phys. Rev. **77**, 50 (1950).

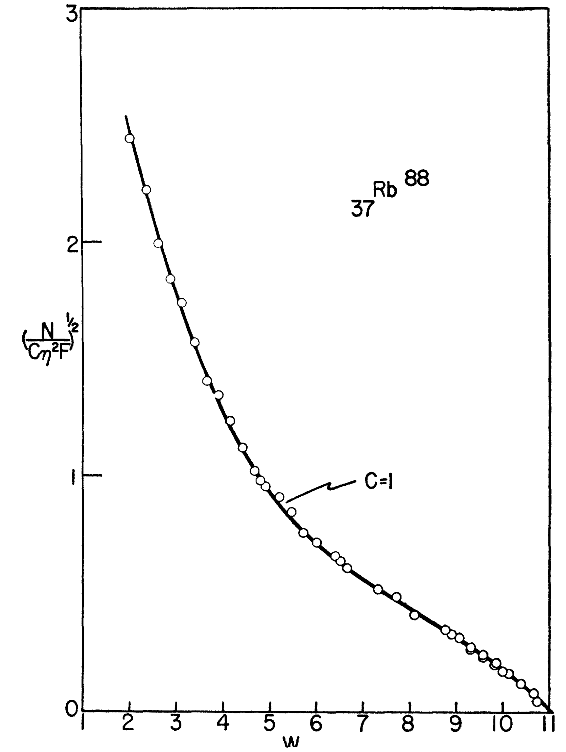

FIG. 2. Conventional Fermi plot. The curve is bent towards the energy axis as it approaches the end point. Values of F were determined from the tables of Moszkowski.

For study of the gamma-radiation, a strong $RbNO_3$ source was irradiated and enclosed in a 0.125-inch walled copper cylinder which stopped all primary beta-radiation. A 0.75-inch diameter, 56-mg/cm² uranium radiator covered the front end of the cylinder.

The sources were irradiated with slow neutrons from a nuclear reactor. Times of irradiation and of the spectrometer runs were chosen so that there resulted no interference from other activities. The radioactive decay of a dummy source was monitored during the spectrometer runs, and the decay period was checked in the spectrometer at various energies. The half-life was measured as 17.8±0.2 min.

III. RESULTS

Figure 1 is a momentum plot of the electron spectrum or Rb^{88}. The obviously complex shape has been resolved into three beta-ray groups on the basis of a Fermi analysis of the data. Figure 2 shows the conventional Fermi plot. In addition to the rise at low energy, there is at high energies a distinct deviation from the straight line characteristic of an allowed transition. The forbidden factor $a=W^2-1+(W_0-W)^2$, applicable to once forbidden transitions with spin change of two units, has been applied to the data and yields the straight line shown in Fig. 3. By appropriate subtractions, the spectrum has been resolved into three groups. The two inner groups are assumed to have the allowed shape. This analysis results in maximum beta-ray energies of 5.13±0.03, 3.29±0.10, and 2.04±0.15 Mev, with corresponding intensities of 66, 19, and 15 percent. The resulting momentum distributions are shown in Fig. 1. The comparative half-lives for the transitions are respectively $\log ft=7.3$, 7.0, and 6.2. It is of interest to note that f, the integral of the *allowed* transition probability over the energy, must here be modified by the factor $a=W^2-1+(W_0-W)^2$. The product $(W_0^2-1)ft$ is then a better indication of the comparative half-life[9] and for transitions with a parity change and spin change of two units should have a value 10^{10}. For the high energy group from Rb^{88}, $(W_0^2-1)ft=0.24\times10^{10}$. Figure 4 shows the observed distribution of photo- and Compton electrons from the uranium radiator. There is evidence of a K photo peak corresponding to a gamma-ray of 0.90 Mev. In addition, a gamma-ray energy of 1.85 Mev is determined by means of the second photo peak and also from the Compton edge. The high energy Compton tail gives a gamma-ray energy of 2.8 Mev.

IV. CONCLUSIONS

The three beta-ray groups of 5.13, 3.29, and 2.04 Mev, together with the observed gamma-ray energies of 0.90, 1.86, and 2.8 Mev, suggest the decay scheme shown in Fig. 5. The 1.86-Mev gamma-ray fits well the energy difference between the two highest energy beta-groups. The level in Sr^{88} indicated by the 2.04-Mev beta-ray is somewhat higher than the gamma-rays of 0.90 and 2.80 Mev would substantiate. Levels in Sr^{88} have been determined by Peacock and Jones[7] in studying the decay of Y^{88} by K capture and positron emission. They

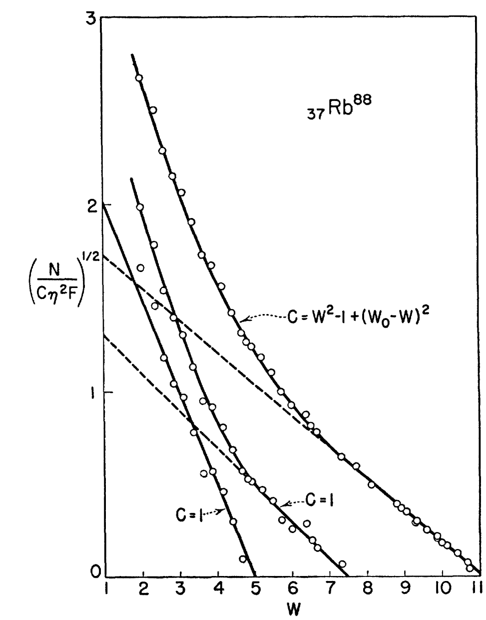

FIG. 3. Forbidden Fermi plot of the data and results of two successive subtractions. It is assumed that the spectra of the inner groups are of the allowed form.

[9] F. B. Shull and E. Feenberg, Phys. Rev. 75, 1768 (1949).

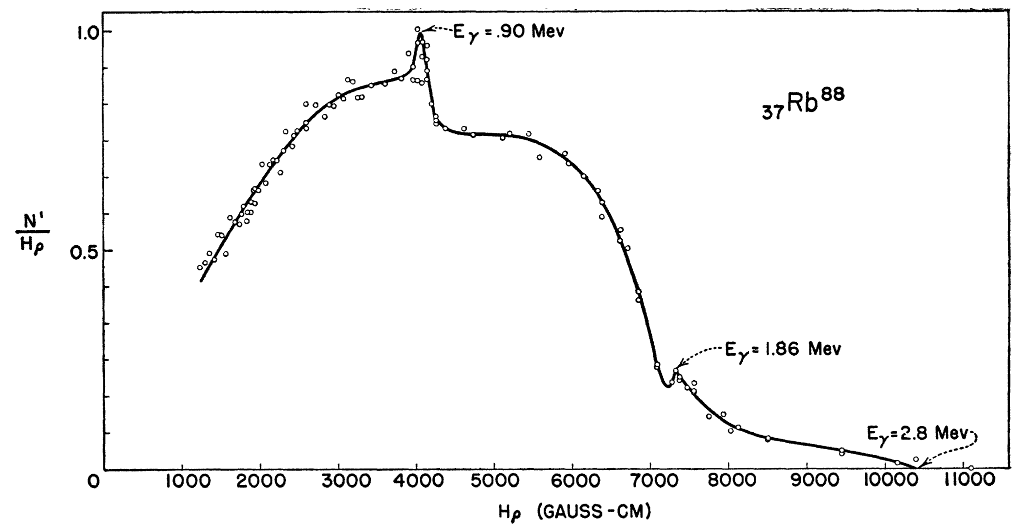

FIG. 4. Compton and photo-electrons ejected from a uranium radiator by the gamma-rays following the decay of Rb^{88}.

found gamma-rays at 0.908, 1.853, and 2.76 Mev. These values are in excellent agreement with the gamma-rays from Rb^{88}. Since the value of 2.04 Mev is the result of two subtractions in the Fermi analysis, it is possible that the error is greater than 0.15 Mev and that the softest beta-ray group actually feeds the 2.8-Mev level. A search for a gamma-ray of about 0.3 Mev which would bridge the energy difference gave negative results.

The spectrum shape of the high energy beta-ray group indicates that the transition is once forbidden

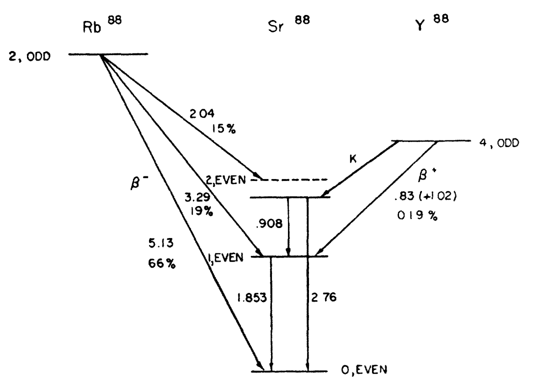

FIG. 5. Disintegration scheme of Rb^{88} and Y^{88} and energy levels of Sr^{88}.

with a spin change of two units; and, since the product nucleus $_{38}Sr^{88}$ is *even-even* and hence presumably has *even* parity and spin 0, *odd* parity and spin 2 may be assigned to the ground state of Rb^{88}. Furthermore, *even* parity may be assigned to the 1.86- and 2.8-Mev levels in Sr^{88}, since the ft values ($\log ft = 7.0$, 6.2) of the two inner beta-ray groups from Rb^{88} suggest once forbiddenness and hence a parity change. Assignment of *even* parity to these levels contradicts the parity assignments made by Peacock and Jones[7] on the basis of internal conversion coefficients. However, more recent calculations of the internal conversion coefficients[10] permit a reinterpretation of the data of Peacock and Jones. Their measurement of the 1.853-Mev gamma-ray is consistent with magnetic dipole radiation and would indicate spin 1 and even parity for the 1.8-Mev level. The reported conversion of the Y^{88} 0.908-Mev gamma-ray is less than the theoretical electric dipole value and must be assumed to be in error. Peacock and Jones' assignment of spin 2 for the 2.8-Mev level in Sr^{88} is still justified on grounds of the relative intensities of positron emission and K electron capture in Y^{88}.

Consideration of the one-particle spin-orbit coupling model,[11] extended to odd-odd nuclei,[12] suggests a spin of 4 and odd parity for the ground state of Y^{88}. This is the result of $p_{1/2}$ for the 39th proton and $g_{9/2}$ for the 49th neutron. These assignments agree both with the order of energy levels obtained theoretically and with the measured spins of Y^{89} and Sr^{87}, for which Z and N respectively are the same as for Y^{88}.

The shell model prediction for the ground state of Rb^{88} is less certain. The 37th proton and 51st neutron are predicted as $p_{3/2}$ and $g_{7/2}$ respectively. The spin of Rb^{87} with 37 protons and Sb^{123} with 51 protons have been measured and substantiate these assignments. However, Rb^{85} and Zn^{67} exhibit $f_{5/2}$ for the 37th nucleon while Sb^{121} and Zr^{91} show $d_{5/2}$ for the 51st nucleon. Thus four possible combinations result in odd parity and *permit* a spin of two units. The $p_{3/2}-g_{7/2}$ combination predicts odd parity and spin 2 uniquely and seems most probable.

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[10] M. E. Rose, tables privately circulated.
[11] M. G. Mayer, Phys. Rev. **78**, 16 (1950).
[12] L. W. Nordheim, Phys. Rev. **78**, 294 (1950).