Radioactivity of Co^{57}

BERND CRASEMANN AND D. L. MANLEY*
Department of Physics, University of Oregon, Eugene, Oregon
(Received December 24, 1954)

Co^{57}(270-day) has been prepared by the reactions $Mn^{55}(\alpha,2n)$ and $Ni^{58}(p,2p)$, separated chemically, and its disintegration studied with a magnetic lens and a scintillation spectrometer. Co^{57} decays by electron capture; an upper limit of 2×10^{-5} positron per disintegration has been set. Positron groups previously assigned to Co^{57} presumably belong to one of the neighboring isotopes of cobalt. Gamma rays of 0.137 and 0.123 Mev have a relative abundance of 7 and 93 percent, and presumably are $E2$ and $M1$ transitions, respectively. A decay scheme is outlined.

I. INTRODUCTION

COBALT-57 (270-day) was first reported by Livingood and Seaborg,[1] who measured a positron energy of 0.26 Mev by absorption. Plesset[2] found highly converted gamma rays of 0.130 and 0.117 Mev in the decay of this isotope. The energy of these gamma rays was found to be 0.131 and 0.119 Mev by Elliot and Deutsch[3] and 0.138 and 0.123 Mev by Alburger and Grace,[4] who also measured their conversion coefficients. Deutsch and Wright[5] reported a 0.014-Mev excited state, of half-life 1.1×10^{-7} sec, of the Fe^{57} daughter of Co^{57}. Cheng, Dick, and Kurbatov[6] assigned a 0.320-Mev positron transition to the disintegration of Co^{57}.

In order to establish a decay scheme for Co^{57}, it seemed desirable to re-examine the positron spectrum of this isotope and to search for possible branching. For this reason, the present work was undertaken.

II. APPARATUS

The thick magnetic lens beta-ray spectrometer used in the present work is of the Siegbahn type[7] and has a resolution of 3.1 percent. A helical baffle of aluminum allows transmission of only positrons or only electrons, depending on the direction of the current in the magnet coils. By this device, a positron spectrum can be studied without interference from conversion electrons. The magnet current is electronically controlled to one part in 10 000. The current regulator, designed by K. D. Jenkins of the University of California, consists of a comparison network, dc chopper, push-pull ac amplifier with a gain of 200 000, and a full-wave power phase detector whose output is directly applied to the field of a dc generator. The magnet current is measured by determining the voltage drop across a 0.01 ohm standard resistor with a Leeds and Northrup 7552 potentiometer.

The detector consisted, for some runs, of a laboratory made Geiger tube with a 0.67 mg/cm² window of DuPont Mylar, and for the remaining runs, of a Victoreen 1B67 tube with a 2.1-mg/cm² mica window. In the latter case, corrections for window absorption were applied to the data. The correction factors were taken from the curves of Saxon,[8] which had been supplemented with experimental points derived from a Fermi plot of the electron spectrum of S^{35}.

The spectrometer was calibrated by means of the 0.6242-Mev conversion electrons[9] from Cs^{137} and the 0.0620-Mev conversion line[10] from Cd^{109}. Hysteresis effects, amounting to 7.3 gauss-cm, were taken into account.

III. PREPARATION OF SOURCES

Two methods were used for preparing Co^{57}. "Sample I" was obtained in the following manner: Manganese, electrolytically deposited on a copper probe, was bombarded with approximately 100 μa-hr of 32-Mev alpha particles in the University of California's Crocker Laboratory cyclotron, in order to produce Co^{57} by the reaction $Mn^{55}(\alpha,2n)$. The manganese layer was dissolved in 8N HCl containing Co carrier, and Ga and Fe were extracted with β,β'-dichlorodiethylether. The solution was boiled to dryness, the residue redissolved in water and made slightly acidic in HCl. The cobalt was precipitated with hot α-nitroso-β-naphthol in 50 percent acetic acid. The precipitate was washed, and the organic molecule destroyed by boiling with a mixture of nitric and perchloric acids. The precipitation and destruction of cobalti-nitroso-β-naphthol was repeated. The cobaltous perchlorate was finally dissolved in a small quantity of water and the solution evaporated onto 20–30 μg/cm² Tygon films held by Lucite sleeves, for mounting in the spectrometer. Through two independent chemical separations, three spectrometer sources were prepared from sample I, ranging in thickness from 50 to 300 μg/cm².

"Sample II" consisted of 1 millicurie of Co^{57} obtained from the Radioisotopes Sales Department of the Oak Ridge National Laboratory. It had been produced by

* Present address: Department of Radiological Physics, University of Rochester, Rochester, New York.

[1] J. J. Livingood and G. T. Seaborg, Phys. Rev. **60**, 913 (1941).
[2] E. H. Plesset, Phys. Rev. **62**, 181 (1942).
[3] L. G. Elliot and M. Deutsch, Phys. Rev. **64**, 321 (1943).
[4] D. E. Alburger and M. A. Grace, Proc. Phys. Soc. (London) **A67**, 280 (1954).
[5] M. Deutsch and W. E. Wright, Phys. Rev. **77**, 139 (1950).
[6] Cheng, Dick, and Kurbatov, Phys. Rev. **88**, 887 (1952).
[7] K. Siegbahn, Phil. Mag. **37**, 163 (1946).
[8] D. Saxon, Phys. Rev. **81**, 639 (1951).
[9] Muller, Hoyt, Klein, and DuMond, Phys. Rev. **88**, 775 (1952).
[10] Cork, Rutledge, Stoddard, Branyan, and LeBlanc, Phys. Rev. **79**, 938 (1950).

the bombardment of nickel with 22-Mev protons. Spectrometer sources of varying strengths were prepared from this sample in the same manner as described above.

IV. GAMMA-RAY SPECTRUM

The gamma rays of Co^{57} were studied by investigating the distribution of internal conversion electrons, using the spectrometer baffle to discriminate against positrons. A detail of the conversion electron spectrum is reproduced in Fig. 1. It yields energies of 0.137 ± 0.002 Mev, for γ_1, and 0.123 ± 0.002 Mev, for γ_2. These energy values agree, within the limits of error, with the values determined by Alburger and Grace.[4] The energy of γ_3, reported by Deutsch and Wright[5] as 0.014 Mev, was not redetermined directly. A survey with a scintillation spectrometer revealed no other gamma rays in the range from 0.05 to 0.6 Mev.

The areas under the conversion electron peaks were planimetered on a plot of N/η *vs* i. The ratio of the number of conversion electrons of γ_2 to that of γ_1 was thus found to be 1.0 ± 0.2. This corresponds to a value of 13 ± 5 for the intensity branching ratio $I(\gamma_2)/I(\gamma_1)$, computed with Alburger and Grace's values[4] for the conversion coefficients.

V. POSITRONS

The positron spectrum of the cobalt samples was measured in the magnetic lens spectrometer, with conversion electrons eliminated by the helical baffle. Figure 2 shows a Fermi plot of the data from sample I. Admixtures of Co^{56} and Co^{58}, from the $Mn^{55}(\alpha,3n)$ and $Mn^{55}(\alpha,n)$ reactions, produce components with end points of 1.50 and 0.47 Mev, respectively, that have been previously reported by other investigators.[11] A positron component with maximum energy of 0.312 ±0.020 Mev is presumably identical with a 0.320-Mev group observed by the Ohio State workers.[6] The

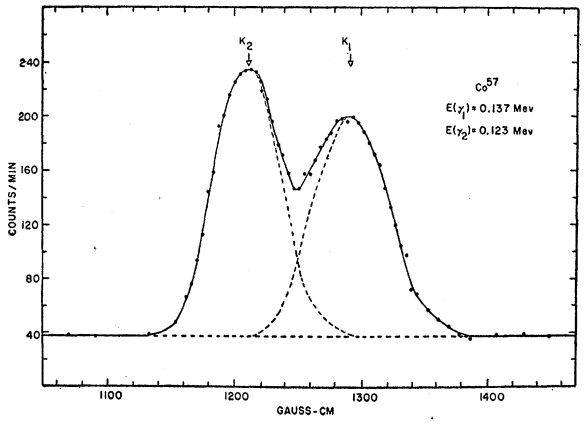

FIG. 1. Internal conversion electron spectrum of Co^{57}.

[11] Way, Fano, Scott, and Thew, *Nuclear Data*, National Bureau of Standards Circular 499 (U. S. Government Printing Office, Washington, D. C., 1950) and supplements.

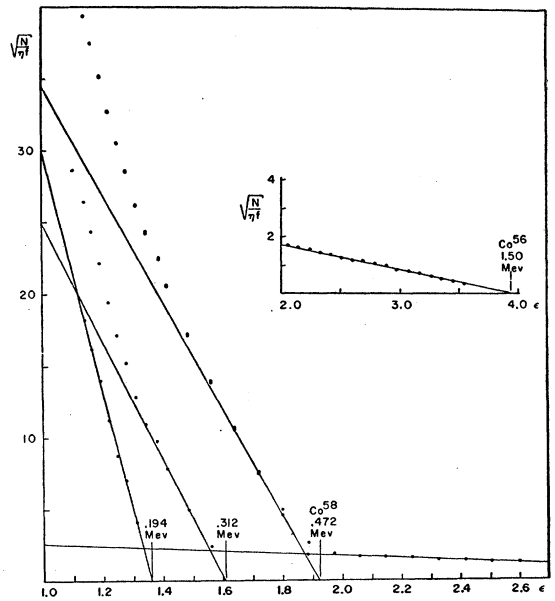

FIG. 2. Fermi plot of the positron spectrum from cobalt isotopes in sample I.

existence of a low-energy group, of 0.194-Mev maximum energy, cannot be considered certain, due to the compounding of errors by multiple subtractions in the Fermi plot, the magnitude of the window correction at low energies, and the possibility of source thickness effects. The 0.312- and 0.194-Mev positron groups were tentatively assigned to Co^{57},[12] following previous work in the literature, but this assignment was proved erroneous by further investigation with sample II, which contained only traces of Co^{56} and Co^{58}. Figure 3 shows the gamma-ray spectrum of Co^{57} from sample II, obtained with a scintillation spectrometer. No annihilation peak is observed. In the magnetic lens spectrometer, no positron group of end-point energy below 0.4 Mev could be found from sample II. Through the use of two sources varying in strength by a factor of 8, an upper limit of 6×10^{-4} positrons of less than 0.4 Mev maximum energy per Co^{57} conversion electron could be set, which corresponds to an upper limit of, approximately, 2×10^{-5} positron per disintegration. If the 0.312-Mev positron transition occurred in the decay of Co^{57}, a ratio of electron capture to positron emission of about 2.2×10^{2} would be expected from theory.[13] It must be concluded, therefore, that the 0.312-Mev positrons and a possible low-energy group belong to one of the neighboring isotopes of cobalt. Work towards their assignment is now in progress in this laboratory.†

[12] The printed abstract of a paper by B. Crasemann and D. L. Manley at the Berkeley Meeting of the American Physical Society, December, 1954 [Bull. Am. Phys. Soc. **27**, No. 8, 31 (1954)] makes use of this assignment. The paper actually read was based on the later results.

[13] E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).

† *Note added in proof.*—The absence of positrons in the decay of Co^{57} has also recently been observed at The Clarendon Labora-

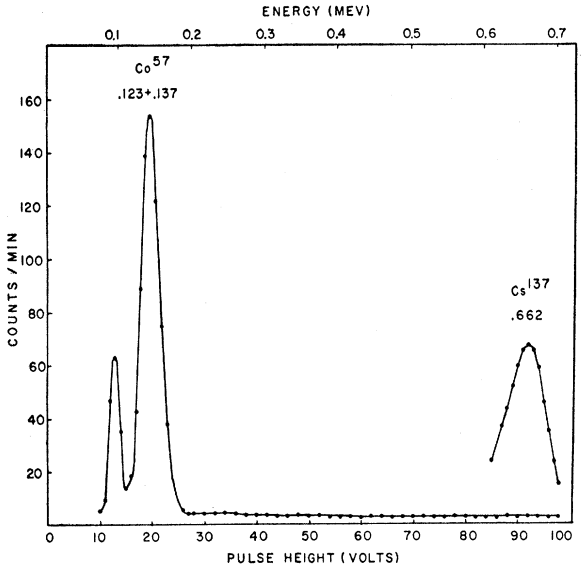

FIG. 3. Gamma spectrum of Co^{57}, sample II. No annihilation peak is observed.

VI. DISCUSSION

The shell model predicts the ground-state proton configuration $(f_{7/2})^7$ for Co^{57}.[14] The spin of this isotope has been measured to be 7/2 by the method of paramagnetic resonance, and its magnetic moment has been determined as 4.6,[15] which is consistent with the shell assignment.[16]

The ground state of Fe^{57}, according to the shell model, should be $p_{\frac{1}{2}}$. This is born out by the angular distribution[17] of the protons from the Fe(d,p) reactions which show that the ground-state group corresponds to the transfer of one unit of orbital angular momentum, so that the ground state of Fe^{57} must have a spin of 1/2 or 3/2 and odd parity. The 0.137-Mev level of Fe^{57} has been reached by Coulomb excitation[18] with 3-Mev alpha particles, with a cross section indicating that this state is most probably reached by an electric quadrupole transition.

The 0.137- and 0.123-Mev gamma transitions in Fe^{57}, linking the second excited state with the 0.014-Mev level and the ground state, respectively, have been identified as either $E2$ and $M1$ or $M2$ and $E1$ by Alburger and Grace[4] on the basis of their determination of the conversion coefficients. The results of reference 18 show that the first of these choices is correct, as indicated in Fig. 4.

The first excited state of Fe^{57}, at 0.014 Mev, has a half-life of 1.1×10^{-7} sec, measured by Deutsch and Wright.[5] On this basis, Goldhaber and Sunyar[19] identified the 0.014 Mev transition as magnetic dipole. It follows that the first excited state of Fe^{57} must have the same (odd) parity as the ground state.

The decay scheme shown in Fig. 4 contains two sets of spin assignments for Fe^{57}. While the 3/2–5/2–7/2 set is more likely on the basis of shell-model considerations, the 1/2–3/2–5/2 possibility cannot be excluded with the experimental evidence now available.

VII. ACKNOWLEDGMENTS

The authors wish to express their sincere appreciation to Professor E. G. Ebbighausen, for turning over his spectrometer to them, and to Professor A. C. Helmholz, of the University of California, for obtaining the cyclotron bombardment of the manganese target. Professor Helmholz, Dr. D. E. Alburger, of Brookhaven National Laboratory, and Dr. C. L. McGinnis, of the National Research Council, have kindly read a preliminary report on this work and contributed valuable comments and criticism, for which the authors wish to thank them. Thanks are also due to Dr. H. G. Richter, for advice on the chemical separation of cobalt, to H. D. Osborn, for technical assistance with the construction of equipment, and to K. D. Jenkins, of the University of California's Crocker Laboratory, for advice on the construction of the magnet current regulator of his design.

One of the authors (B.C.) is indebted to the Graduate School of the University of Oregon for two Research Grants that made this work possible.

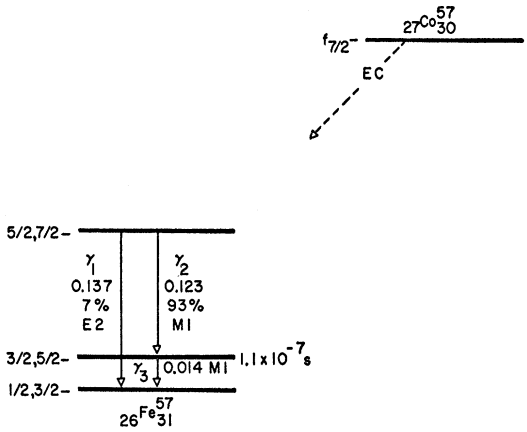

FIG. 4. Decay scheme for Co^{57}.

tory, Oxford, by M. A. Grace, H. R. Lemmer, and O. J. A. Segaert, who obtained an upper limit of 1/1500 positron per disintegration. (Private communication by M. A. Grace.)

[14] P. F. A. Klinkenberg, Revs. Modern Phys. **24**, 63 (1952).

[15] Baker, Bleaney, Bowers, Shaw, and Trenam, Proc. Phys. Soc. (London) **A66**, 305 (1953).

[16] The authors are indebted to Dr. C. L. McGinnis of the National Research Council, Nuclear Data Group, for calling their attention to this work and to that mentioned in the following paragraph.

[17] C. F. Black, Phys. Rev. **90**, 381(A) (1953).

[18] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **95**, 629(A) (1954); Phys. Rev. **93**, 351 (1954), and Phys. Rev. **96**, 426 (1954).

[19] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).