THE
PHYSICAL REVIEW
A journal of experimental and theoretical physics established by E. L. Nichols in 1893

VOL. 62, NOS. 1 AND 2 JULY 1 AND 15, 1942 SECOND SERIES

The Characteristic Radiations of Co^{60}

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(Received April 4, 1942)

The 10.7-minute period previously obtained from Co(n, γ) and Ni(n, p) reactions was produced by a Co(d, p) reaction. The increased activity from this latter reaction made energy measurements possible. The beta-rays were measured with a magnetic spectrometer. In spite of the difficulties caused by the rapid decay of the activity, the best interpretation of the data is that the beta-rays are a continuous spectrum. The end point was evaluated at 1.35±0.1 Mev. Absorption measurements indicated that each beta-ray is accompanied by approximately one gamma-ray of 1.5±0.2-Mev energy. The 5.3-year period radiations previously studied were also investigated and found to consist of a 1.7±0.2-Mev gamma-ray and a 220±20-Kev beta-ray spectrum. These data suggest that Co^{60} may consist of isomeric nuclei in which the two activities decay independently, as an alternative to the previously reported scheme of disintegration.

INTRODUCTION

A RECENT mass spectrographic investigation of cobalt has shown that this element consists of a single stable isotope of mass number 59.[1] It is therefore necessary to consider the slow neutron induced activities, 5.3 years and 10.7 minutes, as isomers with mass number 60. The radiations from the 5.3-year period were first studied by Risser[2] who found a 1.5–2.0-Mev gamma-ray, a beta-ray spectrum with an absorption end point in aluminum at 30 mg/cm², and another weak beta-ray group with an end point at about 650 mg/cm². Later measurements by Livingood and Seaborg,[3] however, indicated that the gamma-ray energy was 1.3 Mev, that the soft beta-rays had a somewhat greater range of 30 mg/cm² to 60 mg/cm², and that the weaker beta-ray group had a range of about 300 mg/cm².

A description of the characteristic radiations of the 10.7-minute period has not been previously reported, probably because of the low yield obtained in Co(n, γ) and Ni(n, p) reactions. It has been suggested,[4] however, that the radiations consist largely of conversion electrons resulting from an isomeric transition from an upper level (10.7 minutes) to a lower level (5.3 years) in Co^{60}. Since it was found possible to produce this activity by a Co(d, p) reaction with an intensity several thousand times that obtained from Co(n, γ) and Ni(n, p) reactions, a further investigation of the radiations was made. The radiations from the 5.3-year activity were also studied in order to determine whether the two periods were genetically related.

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[1] J. J. Mitchell, H. S. Brown, and R. D. Fowler, Phys. Rev. **60**, 359 (1941).

[2] J. R. Risser, Phys. Rev. **52**, 768 (1937).

[3] J. J. Livingood and G. T. Seaborg, Phys. Rev. **53**, 847 (1938).

[4] J. J. Livingood and G. T. Seaborg, Phys. Rev. **60**, 913 (1941).

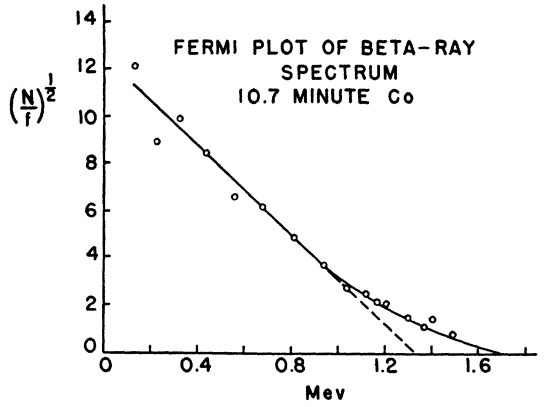

FIG. 1. Fermi plot of 10.7-minute Co^{60} beta-ray spectrum.

THE 10.7-MINUTE PERIOD

The 10.7-minute activity was produced by deuteron bombardment of Hilger No. 11045 V.P.S. cobalt metal. Spectroscopic analysis indicates that the impurities in this metal are nickel in a concentration less than 0.1 percent and traces of copper, chromium, zinc, lead, silver, iron, and calcium totaling about 0.1 percent. The short-lived activities produced from these impurities were present in a very low intensity and did not affect the measurement of the Co^{60} activity, which was verified to decay with a half-life of 10.7 minutes. Hence, no chemical separations were made previous to the energy measurements of the short-lived radiations.

The ratio of the beta-ray and gamma-ray activities as measured with an ionization chamber and Wulf electrometer indicated that approximately one gamma-ray was emitted for each beta-ray. The lead absorption coefficient of the gamma-ray activity was 0.58 cm^{-1}, corresponding to an energy of 1.5 ± 0.2 Mev.

The beta-rays emitted were measured with a magnetic beta-ray spectrometer, which is described elsewhere.[5] It appears from this spectrum that the 10.7-minute beta-rays are continuous. There is some indication of a tail due to recoils from the 1.5-Mev gamma-ray which accompanied the beta-emission. If one allows for this tail the end point is found near $5800 H\rho$ or about 1.3 Mev. A beta-emitter of this energy and half-life gives a point on the first Sargent curve, and therefore the 10.7-minute transition, Co^{60} to Ni^{60}, is probably an allowed transition. The Fermi plot of this spectrum, as shown in Fig. 1, also had a slight tail indicating the presence of gamma-ray recoils. From the momentum distribution and the Fermi plot the end-point energy is evaluated at 1.35 ± 0.1 Mev.

[5] John W. DeWire, M. L. Pool, and J. D. Kurbatov, Phys. Rev. **61**, 564 (1942).

THE 5.3-YEAR PERIOD

The 5.3-year period was also produced by deuteron bombardment of Hilger cobalt. The long-lived activities, which might be produced from the previously mentioned impurities are 250-day zinc, 310-day manganese, 47-day iron, 180-day calcium, and 85-day scandium. These and other elements were chemically separated so that their activities would not mask the soft cobalt radiations. These separations were complicated by the fact that it was necessary to keep the total bulk to a minimum so that thin samples could be prepared.

The activated metal was dissolved in aqua regia with the addition of a few milligrams of tin. The solution was evaporated several times with nitric acid and filtered off to remove any volatile radioactive substances. During this process no carriers were added so that minute concentrations of di- and tri-valent elements were adsorbed by the meta-stannic acid. Since cobalt was present in a weighable quantity (300 milligrams), its loss due to adsorption was negligible.

Carriers of about 50 milligrams each of sodium, calcium, strontium, and barium were added and cobalt was precipitated after oxidation as cobaltic hydroxide by potassium hydroxide. The precipitate was filtered off, washed, and dissolved in nitric acid. One hundred milligrams of the rare earth elements were added and were precipitated as the oxalate and filtered off. The filtrate was evaporated, ignited, and converted into the chloride.

Carriers of 50 milligrams each of the trivalent elements iron and chromium were then introduced and the solution was added to ammonium hydroxide. The precipitate was filtered off and reprecipitated by the same process to avoid any loss of cobalt. Finally carriers of phosphate ions, nickel, zinc, manganese, and other elements which did not interfere with the precipitation of cobalt were added. Cobalt was then precipitated with

α-nitroso-β-naphthol and was converted into Co_3O_4 for measurement. All active impurities separated from cobalt were measured with a G-M immersion tube. When the activities were found to be considerable the chemical separations were repeated.

The lead absorption coefficient of the gamma-ray activity was 0.54 cm^{-1}, corresponding to an energy of 1.7 ± 0.2 Mev. Lower energy gamma-rays were looked for but not observed. Beta-ray ranges in aluminum varied from 44 mg/cm^2 to 55 mg/cm^2, corresponding to an energy of 220 ± 20 kev. As previously reported,[3] the shape of the absorption curve indicated that the beta-rays were probably continuous. The presence of beta-rays with an absorption limit at 300 mg/cm^2 to 400 mg/cm^2 was observed only in samples in which no chemical separations had been made. Hence, it is probable that this group of beta-rays does not belong to Co^{60}.

In order to estimate the relative activities due to the beta- and gamma-rays an ionization chamber filled with Freon at atmospheric pressure and having a 3 mg/cm^2 paper window was used. From the absorption curve taken with this chamber it was estimated that approximately one gamma-ray was emitted for each beta-ray.

The ratio of the activities (5.3-year : 10.7-minute) which would have been produced by an infinitely long deuteron bombardment was greater than 200 : 1. The ratio of the slow neutron cross sections for the two periods[6] (5.3-year : 10.7-minute), when corrected to account for their production from the same stable isotope, is about 40 : 1.

Isomeric decay of the 5.3-year period into the 10.7-minute period is excluded by the fact that no 1.35-Mev electrons are observed in the 5.3-year activity. Isomeric decay of the 10.7-minute period into the 5.3-year period is improbable since this level decays by continuous beta-emission. An interpretation consistent with the data is that Co^{60} consists of isomeric nuclei in which the two activities decay independently.

ACKNOWLEDGMENTS

We wish to express our appreciation to Dr. John W. DeWire for making the spectrometer measurements on the 10.7-minute period. It is a pleasure to acknowledge the support received from Mr. Julius F. Stone, the University Development Fund, and the American Association for the Advancement of Science. Valuable assistance through the W.P.A. cyclotron project No. 65-1-42-89 is also acknowledged.

[6] K. Sinma and F. Yamasaki, Phys. Rev. **59**, 402 (1941)

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Disintegration Schemes of Radioactive Substances. IV. Fe^{59}

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(Received May 8, 1942)

The mode of disintegration of the 47-day isotope of iron Fe^{59} has been investigated by spectrometer and coincidence techniques. The beta-ray spectrum is complex, consisting of two components of approximately equal intensity with end points 0.257 ± 0.008 Mev and 0.460 ± 0.007 Mev. The low energy group is accompanied by gamma-rays of energy 1.30 ± 0.02 Mev, and the high energy group by gamma-rays of energy 1.10 ± 0.02 Mev. No beta-rays of energy greater than 0.460 Mev are present to as much as 0.25 percent of the main group. The yield of Fe^{59} from an iron target bombarded by 12-Mev deuterons is 0.05 microcurie per microampere hour. Methods of purification and preparation are described.

INTRODUCTION

THE 47-day activity induced in iron by deuteron bombardment is uniquely assigned to Fe^{59}.[1] The use of this isotope in biological work has been widespread, although it has been considered a difficult substance to use because of the low energy of the beta-radiation. The widely used dipping counter[2] has recently

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[2] W. F. Bale, F. L. Haven, and M. L. Le Fevre, Rev. Sci. Inst. **10**, 193 (1939).