Decay of Ni^{66}†

NOAH R. JOHNSON, RAYMOND K. SHELINE, AND RICHARD WOLFGANG
Chemistry Department, Florida State University, Tallahassee, Florida
(Received January 30, 1956)

A study of the beta and gamma spectra of the nuclide Ni^{66} has been made. This isotope decays by a single beta ray of 0.20±0.03 Mev, with no associated gammas, to the ground state of Cu^{66}. Both the log(*ft*) value and the shape of the Kurie plot indicate that this transition is allowed, thereby confirming the earlier spin and parity assignments of the ground state of Cu^{66}, and the 1.03-Mev excited level in Zn^{66}.

I. INTRODUCTION

THE nuclide Ni^{66} has been observed to decay with a 56-hour half-life.[1–4] Absorption measurements of its radiation have indicated the presence of a beta particle of about 0.30 Mev.[3] A more thorough study of the beta and gamma spectra of Ni^{66} is reported in this paper, and a decay scheme is proposed.

II. EXPERIMENTAL

Sample Production, Chemical Separations, and Half-Life Determinations

High-energy proton fission of uranium was used to produce Ni^{66} for these experiments. A natural uranium target was bombarded with 340-Mev protons in the University of California 184-in. cyclotron for two hours and then set aside to cool for one day. It was dissolved in HNO_3 and the uranium extracted with tributyl phosphate. After evaporation of the aqueous phase and its conversion to 1*M* HCl solution, about 5 mg of carrier Ni was added and precipitated by dimethylglyoxime. The precipitate was dissolved in 1 ml of concentrated HNO_3 and boiled to destroy the dimethylglyoxime. In succeeding steps carrier Ag^+ was added and precipitated as AgCl, carrier Cu^{++} and Pd^{++} were precipitated as the sulfides from a weak HNO_3 solution, the H_2S was expelled by boiling, and $Fe(OH)_3$ was precipitated from a strongly ammoniacal solution. The nickel was again precipitated by dimethylglyoxime and the entire procedure repeated. To further assure the purity of the nickel activity, a one-ml concentrated HCl solution of the activity was passed through an ion exchange column of Dowex-1 (*X*-10; 100–200 mesh) and eluted with 10*N* HCl.

Cu^{66}, the daughter of Ni^{66}, is known to decay with a 5.2-minute half-life.[5–7] After separation of pure nickel, several minutes were allowed for the Cu^{66} activity to again approach its state of secular equilibrium and the solution was then passed through a Dowex-1 column. A small portion of the resin from the top of column (copper adsorbs strongly from conc. HCl solution) was removed and counted in a Geiger-Mueller counter. The activity decayed with a 5.2±0.1 minute half-life which, after about 10 half-lives, tailed off into a long-lived background of very low activity. This is definite proof for the presence of Ni^{66}.

Using a Geiger-Mueller counter, the decay of the nickel activity was followed through eleven half-lives and in the case of the most highly purified samples was found to yield a single straight-line component. The resulting half-life was 55.1±1.0 hours which is in complete agreement with the previously reported values.[1–4]

Gamma and Beta Spectra

The gamma spectra were taken with a single-channel pulse-height analyzer employing a NaI crystal. Since all spectra involve Cu^{66} in a state of secular equilibrium with the parent Ni^{66}, it was necessary to place a 1.59-gram/cm² aluminum absorber between the sample and the NaI crystal to absorb the high-energy Cu^{66} beta background. Figure 1 shows the spectrum obtained. The 1.03±0.02 Mev peak is the well-defined gamma of Cu^{66}.[5–7] The intense low-energy portion of the curve appears to be due to bremsstrahlung since both its location and intensity change with a change in the *Z* of the absorber. The 1.54-Mev component, the small 0.51-Mev peak, and other small peaks which appeared after considerable decay of Ni^{66} had taken place are attributed to small amounts of long-lived impurities. In a given sample, they remained at almost a constant intensity over a period of several days, but after several more cycles of repurification, they were considerably reduced. The shoulder at 1.34 Mev contains both the Compton peak of the 1.54-Mev group and the radiation from some other shorter-lived impurity. This was probably Ni^{57}, as was indicated by an increase in the apparent peak to Compton ratio with continued decay.

No gammas were observed which could be identified with the 55.1-hour Ni^{66}. From Fig. 1 it is possible to say that any gammas involved in the Ni^{66} decay have an intensity less than 10% of that of the 1.03-Mev group. Both Friedlander and Alburger[5] and Roderick, Meyerhof, and Mann[6] have found that less than 10% of the Cu^{66} betas go to the 1.03-Mev

† This work was supported by the U. S. Atomic Energy Commission.

[1] R. H. Goeckermann and I. Perlman, Phys. Rev. **76**, 628 (1949).
[2] H. H. Hopkins, Jr., Phys. Rev. **77**, 717 (1950).
[3] W. E. Nervik and G. T. Seaborg, Phys. Rev. **97**, 1092 (1955).
[4] Folger, Stevenson, and Seaborg, Phys. Rev. **98**, 107 (1955).
[5] G. Friedlander and D. R. Alburger, Phys. Rev. **84**, 231 (1951).
[6] Roderick, Meyerhof, and Mann, Phys. Rev. **84**, 887 (1951).
[7] D. Maeder and P. Preiswerk, Helv. Phys. Acta **24**, 625, No. 6 (1951).

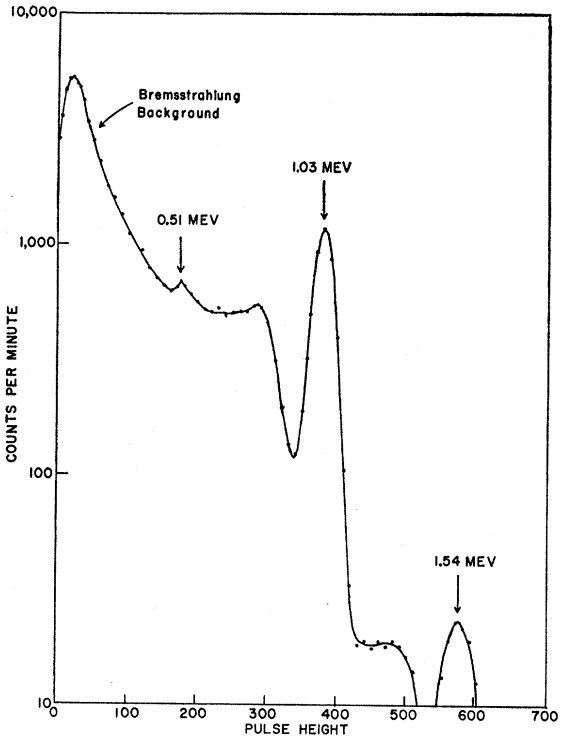

FIG. 1. The gamma spectrum of Ni^{66} and Cu^{66} in a state of secular equilibrium. Se^{75}, Cs^{137}, and Na^{22} were used for calibration.

excited level of Zn^{66}. Consequently, the gamma emission for Ni^{66} is set as less than 1% of the intensity of its 0.20-Mev beta. Booth and Roberts[8] have also failed to find any gammas for Ni^{66}, setting limits of $0.24 < E_\gamma < 3.0$ Mev.

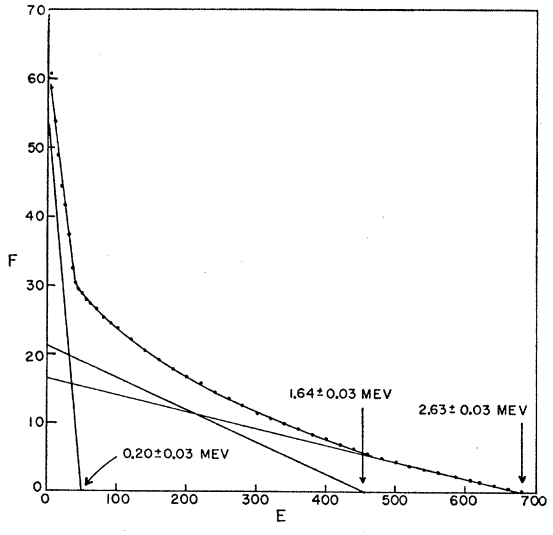

FIG. 2. Kurie plot of the beta spectrum Ni^{66} and Cu^{66}. E is the energy in Mev and F is the allowed Fermi function.

[8] N. E. Booth and D. T. Roberts, Proc. Roy. Soc. (Canada) 48, 29A (1954).

The same single-channel pulse-height analyzer unit was used for the beta spectra. Anthracene crystals served as the scintillator. The nickel samples consisted of thin layers of the chloride or the nitrate deposited on polystyrene film. The high level of activity present made it possible to obtain good statistics on each point in a relatively short counting time.

A Kurie plot of the beta spectrum is shown in Fig. 2. Three beta groups were observed having end-point energies of 2.63±0.03, 1.64±0.03, and 0.20±0.03 Mev. The 2.63-Mev and 1.64-Mev betas are associated with Cu^{66} and have been previously studied in some detail by Friedlander and Alburger[5] and Roderick, Meyerhof, and Mann.[6] There were some indications for a beta group at 0.77 Mev. The shape of the plot remained unchanged after several more cycles of purification, thus indicating that this component is not the result of an impurity. However, such a beta is not compatible with the gamma spectrum of Fig. 1 and the existing information on the decay of the nickel activities. We therefore feel the explanation given by Roderick, Meyerhof, and Mann[6] for a similar group observed in their work is correct. They attributed it to source thickness and inelastic backscattering from the anthracene crystal.

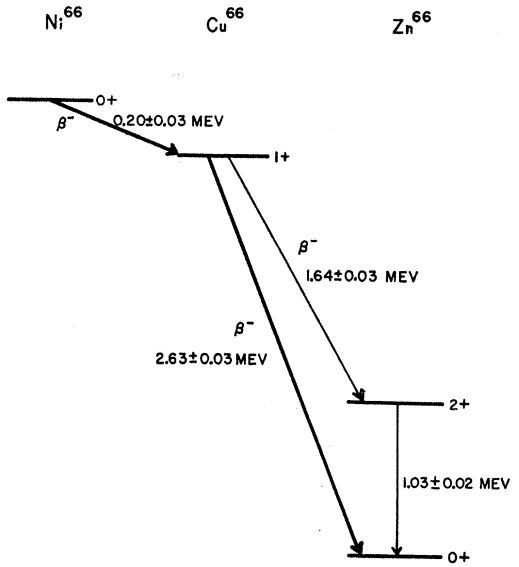

FIG. 3. The decay scheme for the isobaric triplet Ni^{66}-Cu^{66}-Zn^{66}.

The low-energy component of 0.20±0.03 Mev is assigned to Ni^{66} and presumably corresponds to the 0.30-Mev beta previously reported from absorption measurements.[3] No other group was observed which may be associated with this activity. Furthermore, by using the limits set on gamma emission and ruling out the possibilities of a highly internally converted gamma ray and of a long-lived Cu^{66} isomer, it is possible to set an upper limit of 1% for beta branching.

III. DISCUSSION

Ni^{66} is an even-even nucleus and therefore a spin and parity of 0+ can be assigned to its ground state. Using Moskowski's nomograph[9] for *ft* values, the log(*ft*) for the 0.20-Mev beta decay is 3.96, indicating an allowed transition. That this transition is allowed is also shown by the shape of the Kurie plot. As the Gamow-Teller selection rules forbid 0→0 transitions and since the spectra indicate only a single beta and no gammas in the Ni^{66} decay, the Cu^{66} ground level must be 1+. This confirms its earlier assignment as well as the 2+ assignment to the 1.03-Mev level in Zn^{66}.[5,6] The complete decay scheme for the isobaric triplet Ni^{66}-Cu^{66}-Zn^{66} is given in Fig. 3.

[9] S. A. Moskowski, Phys. Rev. **82**, 35 (1951).

From the experimental mass decrements listed by Wapstra,[10] masses of 65.946940±0.000200 and 65.949760+0.000200 are found for Zn^{66} and Cu^{66}, respectively. If one uses an energy of 0.20±0.03 Mev for the difference between the ground states of Ni^{66} and Cu^{66}, a mass of 65.949975±0.000203 is calculated for Ni^{66}.

ACKNOWLEDGMENTS

The authors are most grateful to Dr. Earl Hyde, Mr. Paul Benioff, Mr. Rex Shudde, and the crews of the 184-in. University of California cyclotron, for their cooperation in carrying out the necessary bombardments and for performing the initial stage of the chemical separations.

[10] A. H. Wapstra, Physica **21**, 404 (1955).

PHYSICAL REVIEW VOLUME 102, NUMBER 3 MAY 1, 1956

Gamma-Gamma Angular Correlation in the Decay of Chlorine-34†

HARRY E. HANDLER* AND J. REGINALD RICHARDSON
Physics Department, University of California, Los Angeles, California
(Received January 23, 1956)

The directional angular correlation between the 1.16- and 2.10-Mev gamma rays which follow the decay of 32.4-minute Cl^{34} has been measured. Samples of Cl^{34} were produced in the cyclotron of the University of California, Los Angeles by the (*p*,*pn*) reaction and were produced in both solid and liquid form. Sodium iodide scintillation counters with subsequent pulse-height discrimination and standard coincidence techniques were used and the method was tested on the cascade of Ni^{60} giving satisfactory agreement with previous results. The results on S^{34}, although not unambiguous, are consistent with the assignment of spin 2 and even parity to both the first and second excited states of S^{34} with the 1.16-Mev gamma ray being 1.7% electric quadrupole and 98.3% magnetic dipole radiation.

INTRODUCTION

CHLORINE-34 is a complex positron and gamma-ray emitter which has been the subject of numerous investigations.[1–7]

Figure 1 shows the probable decay scheme of Cl^{34}. The gamma-ray energies are in Mev and are due to Ruby and Richardson[1] and Ticho.[2] Arber and Stahelin[4,6] measured the lifetime of the ground state of Cl^{34} and calculated α, the internal conversion coefficient of the 0.145-Mev gamma ray, from the results of Ruby and Richardson. The values of the half-life of the isomeric state of Cl^{34} and of the maximum energies of the positron groups were reported by Green and Richardson.[7] The gamma-ray intensities were calculated from those of the positron groups and the relative intensities of the 3.22- and 1.16-Mev gamma rays measured by Green[3]; the intensity of the 0.145-Mev radiation includes the percentage which is internally converted.

Arguments based upon all the experimental evidence and upon the fact that S^{34} is an even-even nucleus lead to the choice of spin 2 and even (+) parity for both its excited states as most probable. This investigation of the directional angular correlation between the 1.16- and 2.10-Mev gamma rays was performed to confirm this spin assignment and to determine the ratio of the amplitudes of the electric quadrupole and magnetic dipole radiation in the 1.16-Mev transition. A preliminary and incomplete report of this work has been presented previously.[8]

APPARATUS AND PROCEDURE

The gamma rays were detected by three scintillation counters, one of which served solely as a monitor. The electronic equipment was built following standard

† This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
* Now with General Electric Company, Richland, Washington.
[1] L. Ruby and J. R. Richardson, Phys. Rev. **83**, 698 (1951). References to earlier works are given in this paper.
[2] H. K. Ticho, Phys. Rev. **84**, 847 (1951).
[3] David Green, thesis, University of California, Los Angeles (unpublished).
[4] W. Arber and P. Stahelin, Helv. Phys. Acta **26**, 433 (1953).
[5] W. Arber and P. Stahelin, Helv. Phys. Acta **26**, 584 (1953).
[6] P. Stahelin, Helv. Phys. Acta **26**, 691 (1953).
[7] D. Green and J. R. Richardson, Phys. Rev. **96**, 858 (1954).
[8] H. E. Handler and J. R. Richardson, Phys. Rev. **98**, 281(A) (1955).