If the broad resonant-like structure in the yield of the P_1 group is an intermediate resonance, or "doorway state" in the treatment of Block and Feshbach,[33] then it is natural to expect similar structure in other exit channels. The structure observed in the P_1 group at 9.27 MeV may correspond to the $p_{1/2}$ resonance observed in the elastic scattering[31] at 9.25 MeV. No recognizable corresponding structure is evident in the inelastic scattering to higher excited states (with the possible exception of the P_2 group) in the same energy range. However, the partial widths for exciting the resonance through these states may be too small to be observed in the (p,p') reaction.

VI. SUMMARY

It has been established from the present investigation that compound-nucleus formation dominates the $Ni^{58}(p,p')Ni^{58}$ reaction between 9.1 and 9.55 MeV. The energy-averaged angular distributions (with the exception of the P_1 group) are symmetric about 90° and in reasonable agreement with Hauser-Feshbach calculations for states of known spin. Spins of several other levels are suggested on this basis. The usefulness of this method as a spectroscopic tool appears promising, particularly for $J=0$ and 1 states. Final evaluation of the method's reliability must await further testing on other nuclei and perhaps at lower bombarding energies.

An intermediate-resonance and direct-reaction contribution is observed in the yield of the P_1 group. The calculation employed here was, however, not sufficiently sensitive to establish a unique spin for the resonant structure, as the study of the intermediate-resonance component is complicated by the presence of a direct-interaction contribution.

PHYSICAL REVIEW VOLUME 150, NUMBER 3 21 OCTOBER 1966

Decay of a New Isotope: Cu^{69}†

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(Received 30 March 1966)

Sources of Cu^{69} have been produced by γ-p reactions in Zn (enriched to 78.3% Zn^{70}) and their decay has been studied with scintillation and semiconductor detectors. The half-life of Cu^{69} has been determined to be 3.0 ± 0.1 min. Seventy-nine percent of the decay is by direct beta decay to the ground state of Zn^{69} ($E_0=2.48\pm0.07$ MeV, $\log ft=5.1$). The remaining decay modes exhibit a complex spectrum for which a level scheme has been established. The proposed Zn^{69} levels that are fed by the Cu^{69} decay are at 0.5307, 0.8340, 1.0065, 1.1795, 1.428, 1.825, and 2.026 MeV. Other suggested but more tentative levels are at 0.615, 2.17, and 2.4 MeV. Of the beta-decay modes, those to the 0.5307- and 0.615-MeV levels have the highest $\log ft$ values, namely ~6.7 and 6.8, respectively. The $\log ft$ values of the other branches are smaller than 5.7 and all indicate allowed beta decay.

I. INTRODUCTION

INVESTIGATION of the radioactivities created by photonuclear reactions with a 7-mg Zn sample, enriched to 78.3% Zn^{70}, yielded a previously unreported activity with a half-life of about 3 min. It decayed predominantly by beta decay to the ground state of the daughter nucleus, but the NaI(Tl) scintillation spectrum also showed gamma lines at 1.00, 0.84, and 1.43 MeV and suggested the presence of other weaker lines. The activity was assigned to Cu^{69} and described in a preliminary report.[1] Thereafter, a more complete investigation was made with a larger amount of source material and with improved detection techniques.

For these improved measurements, two samples of metallic Zn with the same enrichment of 78.3% in Zn^{70} were obtained from the Oak Ridge National Laboratory. One, mainly for beta-ray measurements, consisted of 25 mg of metal powder; the other, for the gamma-ray investigation, was a 22.9-mg metal bead.

In the course of the investigation, both samples were irradiated many times with ~200 000 R/min of bremsstrahlung from the 70-MeV Iowa State University synchrotron. Typically, a 3-min irradiation produced about 0.1 μCi activity in these samples. Since the sample container also became activated, it was necessary to transfer the samples after irradiation into another nonradioactive container. The powder was transferred into a gelatin capsule of wall thickness 9 mg/cm², which was grounded by a thin wire. The metal bead was placed in an aluminum (in some cases, brass) container with a wall thickness of 2 mm.

Of the competitive activities created in the sample, the longest living non-negligible one is the 14-h isomeric transition of 0.439 MeV in Zn^{69}. The dominant (γ,n)

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† Work performed in the Ames Laboratory of the U. S. Atomic Energy Commission, Contribution No. 1867.

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[1] J. Van Klinken, A. J. Bureau, and R. J. Hanson, Bull. Am. Phys. Soc. 10, 1117 (1965).

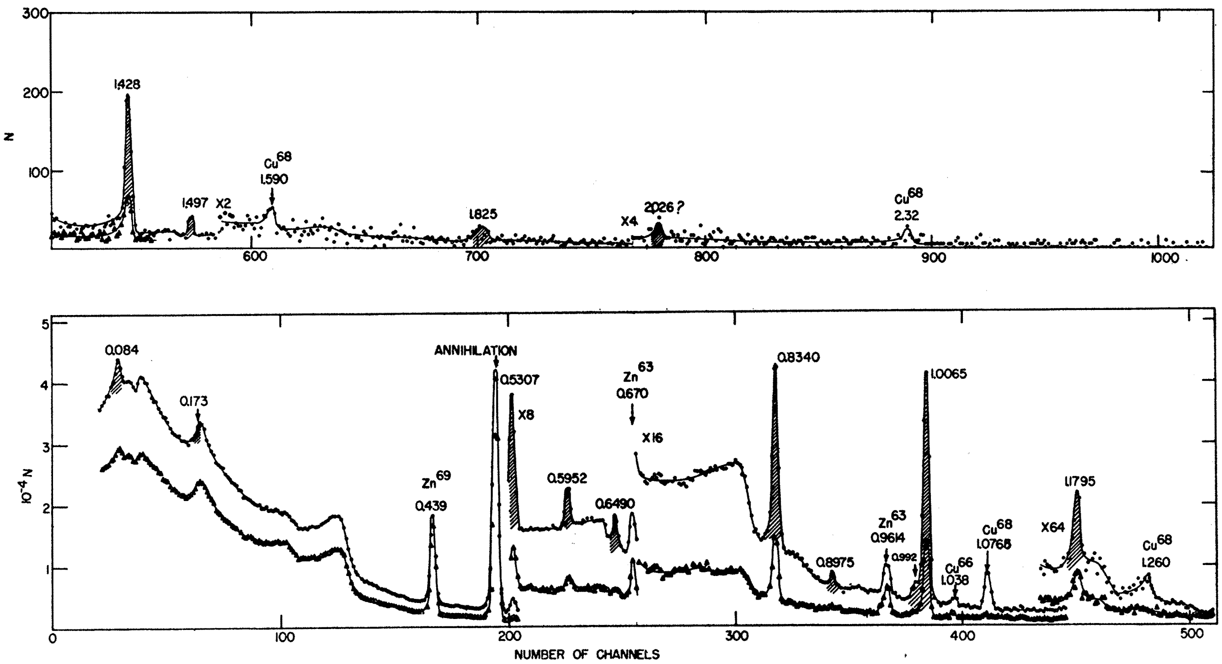

FIG. 1. Ge(Li) spectrum. Upper curves: Counts during first 2.5-min counting period. Lower curves: Counts during second 2.5-min counting period, started 5.0 min after start of the first period. Peaks assigned to Cu^{69} are shaded.

reaction also produces 55-min Zn^{69}, which fortunately decays only by beta emission. Other impurities are: 38 min Zn^{63} [produced by (γ,n) reactions with Zn^{64} which constitutes 7.7% of the enriched sample], 30-sec Cu^{68} from $Zn^{70}(\gamma,np)$, 5.1-min Cu^{66} from Zn^{67} (γ,p), and 2.1-min O^{15} [produced by (γ,n) from O^{16} which was present as a chemical contaminant in the samples]. The gamma rays from these contaminations do not interfere seriously with those of Cu^{69}, except for the annihilation radiation from Zn^{63} and O^{15}. This radiation obscures observations around and below 0.511 MeV. Of the competitive beta rays, those from Zn^{69} and Zn^{63} are predominant and make beta-ray measurements difficult.

TABLE I. Observed gamma transitions. ϵ = estimated intrinsic full energy peak efficiency of the Ge(Li) detector used.

Energy (MeV)	ϵ %	Relative intensity	Remarks from following sections
0.084 ±0.001	40	4	Coinc. with 0.5307 MeV
0.110 ±0.002	39	≤2	Not assigned in decay scheme
0.173 ±0.002	17	≤3	Fits in energy between 1.0065 and 0.8340 MeV
0.5307±0.0003	1.7	30	Coinc. with 0.649, 0.8975, and 1.497 MeV
0.5952±0.0005	1.4	10	Is not a transition to the groundstate.
0.6490±0.0005	1.1	~14	
0.8340±0.0005	0.68	62	Coinc. with 0.5952 and 0.992 MeV
0.8975±0.001	0.60	3	
0.992 ±0.001	0.55	6	
1.0065±0.0008	0.50	100	No clear coincidences
1.1795±0.001	0.36	10	No clear coincidences
1.428 ±0.001	0.24	9	No clear coincidences
1.497 ±0.003	0.22	1	
1.825 ±0.005	0.16	1	Shows some summing
2.026 ±0.008	0.14	≤0.5	Shows summing
2.17 ±0.02		≤0.3	Observed with NaI(Tl) only
2.4 ±0.1		≤0.3	No clear summing effects

II. HALF-LIFE

The half-life of Cu^{69} was first measured by following the decay rate for different parts of the beta-ray spectrum and for prominent lines in the NaI(Tl) gamma-ray spectrum. Our estimate from these data is $T_{1/2}=2.8\pm0.3$ min. The uncertainty was mainly due to interference from 0.5 min Cu^{68}, 5.1 min Cu^{66}, 38 min Zn^{63}, and a rather unknown amount of 2.1 min O^{15}. More reliable information has been derived from the decay rate of the most intense gamma-ray transition at 1.0065 MeV as observed with the Ge(Li) detector. With this detector the line is distinctly separated and its correction for background is small. From the ratio of numbers of counts during time intervals t_1-t_0 and t_3-t_2:

$$N(t_1-t_0)/N(t_3-t_2)=(e^{-\lambda t_0}-e^{-\lambda t_1})/(e^{-\lambda t_2}-e^{-\lambda t_3}),$$

three independent values for $T_{1/2}=(\ln 2)/\lambda$ were obtained: 2.9±0.1, 3.1±0.1, and 3.05±0.1 min. As our final value, we quote $T_{1/2}=3.0\pm0.1$ min.

III. GAMMA-RAY SPECTRA

In the NaI(Tl) scintillation spectrum only the prominent gamma-ray lines are observable. The complex gross spectrum, however, has been resolved into a large

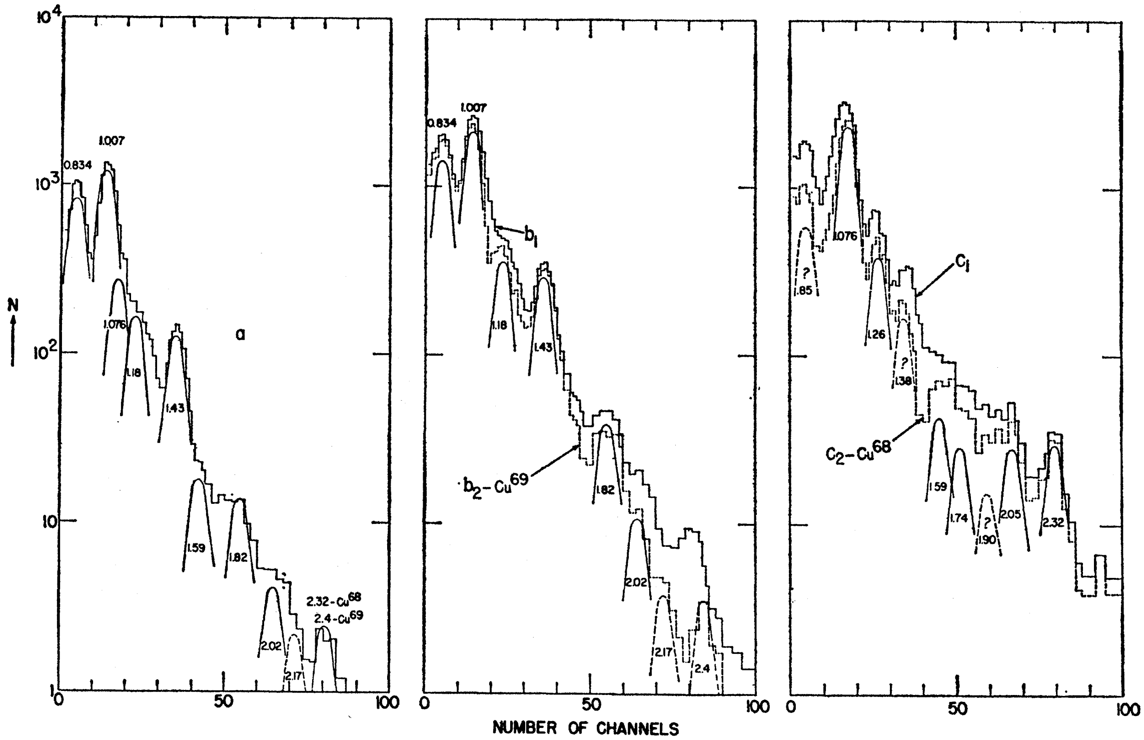

FIG. 2. NaI(Tl) spectra above 0.75 MeV. (a) Sample 7 cm from detector with enhanced 3-min activity; (b) and (c) sample 0.7 cm from detector; $(b)_1$ enhanced 3-min activity, $(b)_2$ residual Cu^{69} after subtraction of Cu^{68}, $(c)_1$ enhanced 0.5-min activity, $(c)_2$ residual Cu^{68} after subtraction of Cu^{69}.

variety of separate lines by using a lithium-drifted germanium detector with 5.5-keV resolution at 1 MeV. This detector was an RCA, SJGG-5/30 with an effective volume of 1.5 cm^3. It was connected through a Tennelec 100C preamplifier and a TC 200 low-noise amplifier to a Victoreen 1024-channel analog-to-digital converter (ADC). The ADC output was fed into an SDS-910 computer where storage could be routed into any one of four memories of 1024 channels each.

The relative intrinsic full-energy-peak efficiency for this Ge(Li) detector was determined by measuring the counter response to well-known sources like Yb^{169}, Bi^{207}, Na^{22}, and Th^{228}, placed 2 cm from the detector. The accuracy of the adopted values of the efficiency (Table I) is not better than 10% and is probably poorer below 100 keV. This calibration agrees with curves obtained by Ewan and Tavendale[2] if differences in counter volume, geometry, and encapsulation are taken into account. For our detector the stainless-steel encapsulation decreases the efficiency rapidly for energies below 100 keV. The energy calibration was obtained with standard sources like Bi^{207}, Th^{228}, and Co^{60}. Recently Murray *et al.*[3] reported four accurate values of gamma-ray energies in the last two sources: 583.139±0.023 keV, 2614.47±0.10 keV, 1173.23±0.04 keV, and 1332.48±0.05 keV. The most reliable calibration point, however, came from annihilation radiation from Zn^{63}, which was always present as an impurity in the sample. Therefore, the energy assignment is most accurate around 500 keV. At higher energies the energy determination was hampered by poor statistics and also (but only during long accumulative runs) by drift in the electronic gain. We followed the position of the Bi^{207} line at 1.0639 MeV for some days and noticed that its shift was less than 1.9 keV per day, but negligible during short measurements within a few Cu^{69} half-lives. The least-squares fit of the standard lines demonstrated always the well known excellent linearity of a Ge(Li) detector.

In view of the low efficiency of the Ge(Li) detector, we adopted a method of cumulative counting during several successive runs with the sequence: 2.5-min irradiation of the Zn bead, 2.5-min counting (starting ~40 sec after irradiation) with data storage in the first memory, 2.5-min waiting and again 2.5 min counting with storage in the second memory. Thereafter, the bead was immediately irradiated for a subsequent run. The spectra shown in Fig. 1 are the results of 16 runs. After these cumulative runs the decay of the sample was observed for several days (no spectra are shown) in order to follow longer lived components. Gamma-ray transitions from the decay of Cu^{69} could easily be identi-

[2] G. T. Ewan and A. J. Tavendale, Can. J. Phys. **42**, 2286 (1964).
[3] G. Murray, R. L. Graham, and J. S. Geiger, Nucl. Phys. **63**, 353 (1965).

fied by their decay rate, since no other transitions with a half-life close to 3 min were found in the sample.

The cumulative counting works very well above 0.511 MeV but the method is less advantageous around and below this energy because of enhancement of the 38-min annihilation radiation and its Compton distribution. For this low-energy range the spectra of the first run only showed slightly more detail, but suggested only the 0.110-MeV line in addition to those indicated in Fig. 1. A list of energies and intensities of gamma-ray lines assigned to the decay of Cu^{69} is given in Table I. The precise energy determination made it possible to use the Ritz combination principle of looking for adjacent cascade transitions whose combined energies are, within limits of error, equal to the energy of a crossover transition. A close inspection of Table I suggests several combinations of this type, many of which were confirmed by coincidence measurements. A spurious peak or enhancement of a peak due to summing in the sense that the full energies of two coincident gamma-ray quanta are simultaneously detected, is negligible for the Ge(Li) detector used.

With a conventional 3-in.×3-in. NaI(Tl) detector additional information has been obtained for higher energies where the efficiency of this counter is superior to that of the Ge(Li) counter and where summing effects become observable. The detector assembly was connected with a 400-channel RIDL analyzer. For the spectra presented in Fig. 2 the low-energy bias was set above the intense annihilation radiation in order to reduce the dead time in the 400-channel analyzer. The same procedure of cumulative counting as mentioned above was repeated. For the curve of Fig. 2(a), obtained with the source placed 7 cm from the NaI(Tl) crystal, counts from six successive runs were added; for the curve $(b)_1$, obtained with the source only 0.7 cm from the detector, four runs were added. However, these curves are *difference* spectra, obtained by subtracting the counts in the second 2.5-min run (containing mainly long-lived components) from those in the first 2.5-min run, which was started 5 min before. In these *difference* spectra the short-lived Cu^{69} and Cu^{68} components are strongly enhanced. The 0.5-min Cu^{68} influence has been studied with still shorter irradiation, counting, and waiting periods of 30 sec each. The results for this neighboring isotope are shown in Fig. 2(c) but will be discussed in the Appendix. They allow us to subtract the influence of Cu^{68} and show that the peak around 2.32 MeV is mainly from this decay. After the subtraction, Fig. $2(b)_2$ still shows evidence for peaking at 2.02, 2.17, and ~2.4 MeV. Here the less efficient Ge(Li) shows no clear structure but only a slight peaking around 2.026 MeV, which remained after subtraction of long-lived activities. The scintillation spectra have been analyzed by hand in their main components, as drawn in Fig. 2, without including all the weaker lines known from the Ge(Li) spectra.

Comparison of the curves a and b_2 of Fig. 2 reveals a moderate summing effect for the 1.82-MeV line. This can be explained by a cascade relationship for the 0.8340- and 0.992-MeV lines. On the other hand, the possibility of cascading of the two most intense transitions of 1.0065 and 0.8340 MeV can be ruled out since that would yield a much more intense sum peak at 1.84 MeV. Because of their large intensities, it is thus very likely that the 1.0065- and 0.8340-MeV lines represent levels in the decay scheme, since all the other reported transitions are of distinctly lower intensity.

The peak at 2.02 MeV also shows summing, which can be attributed to 0.5307+1.495 MeV. However, there is little evidence for summing for the still weaker and tentative lines at 2.17 and 2.4 MeV.

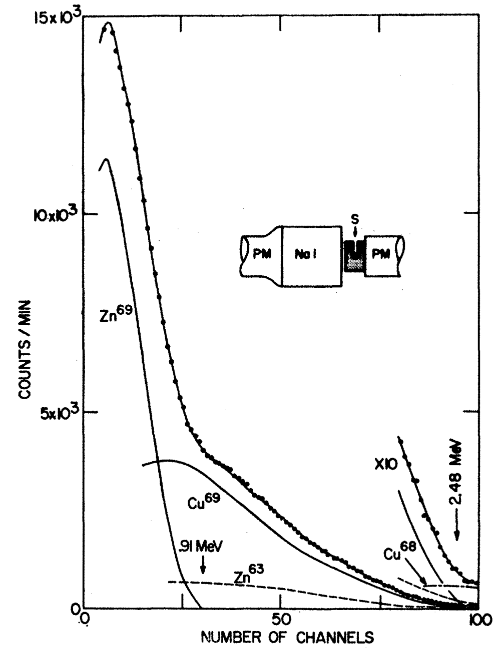

FIG. 3. Gross beta spectrum.

IV. THE GROSS BETA-RAY SPECTRUM

Accurate measurement of the beta-ray spectrum of Cu^{69} has not been possible because of the presence of beta rays from Zn^{69} (55 min, $E_0=0.91$ MeV), Zn^{63} (38 min, $E_0=2.34$ MeV), and Cu^{68} (30 sec, $E_0=4.8$ MeV), and because of the large average thickness of the powder source of probably more than 30 mg/cm^2.

As a 4π beta-ray spectrometer, useful also for $\beta-\gamma$ coincidence measurements, a well-type plastic scintillator was used. The cylindrical plastic detector (Pilot B, 1-in.×1.5-in. diam) had a well of 0.23-in. diam drilled from the side, perpendicular to its axis and equidistant from the ends. The powder source S inside the thin gelatin capsule of 9-mg/cm^2 wall thickness was placed in the well, as shown in the inset of Fig. 3. The detector had a resolution of 19% for 0.976-MeV electrons and

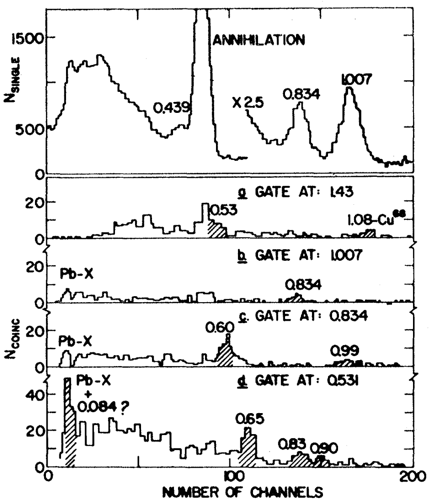

FIG. 4. Gamma-gamma coincidences.

yielded a reasonably straight Fermi-Kurie plot for calibration sources like Y^{90} and P^{32}.

For the gross beta-ray spectrum of Fig. 3, a 2-min counting period was started 1 min after a 2-min irradiation. The analysis of this spectrum into its different components was made by following the decay of the sample. No useful Fermi-Kurie plot can be obtained in this way because of the reasons mentioned above but also because of γ-ray interference. The adopted arrangement was convenient, however, for determining the relative amount of beta decay to the ground state. For this a 3-in.$\times$3-in. NaI(Tl) counter was placed face to face with the plastic. By observing the gamma-ray spectrum and the gross plastic scintillation spectrum simultaneously, it was possible to estimate the ratio R of the number of emitted 1.0065-MeV gamma-ray quanta to the total number of Cu^{69} disintegrations. The number of 1.0065-MeV gamma quanta emitted was obtained from the number of counts in the photopeak corrected for NaI(Tl) efficiency, geometry, and absorption in the plastic between the source and NaI(Tl) crystal. The number of total Cu^{69} disintegrations followed from analysis of the gross plastic-scintillation spectrum as shown in Fig. 3. In three independent trials, the following values were found for R: 0.09 ± 0.03, 0.095 ± 0.02, and 0.16 ± 0.04, yielding a weighted average value of $R=0.10\pm0.02$. Since the 1.0065-MeV transition is the most intense, it follows that the Cu^{69} decay is predominantly direct beta decay to the ground state of Zn^{69}.

Figure 3 shows that around the endpoint of the beta-ray spectrum, the presence of Cu^{68} and Zn^{63} inteferes seriously with an accurate determination of the total disintegration energy E_0. As a best estimate from three different measurements (the endpoint energy of 2.27 MeV for Y^{90} was used for calibration in each case) we quote: $E_0=2.48\pm0.07$ MeV. The value is in close agreement with a predicted value of about 2.3 MeV from shell-model systematics of mass differences.[4]

V. COINCIDENCE MEASUREMENTS

It has been possible to make some useful β-γ and several γ-γ coincidence measurements with standard fast-slow coincidence circuitry using NaI(Tl) and plastic scintillation counters. We used Sturrup Modular equipment (101 Amplifiers, 501 F.S. discriminator and single-channel analyzers, and 1401 F.S. coincidence base unit) with resolving times between 50 and 150 nsec.

The β-γ coincidences were made with the powder source placed inside the plastic well detector and the NaI(Tl) crystal close to and face to face with the plastic. When counts from the entire beta-ray spectrum were used for gating, we obtained a gamma-ray coincidence spectrum which was nearly the same as the gross gamma-ray single spectrum, except of course that the 14-h Zn^{69} isomeric transition of 0.439 MeV disappeared. It follows that none of the other visible lines results from metastable levels with lifetimes longer than 0.1 μsec. Gamma-ray spectra taken in coincidence with higher energy beta rays show that the prominent lines at 0.8340 and 1.0065 MeV coincide with relatively high-energy beta rays of more than 1 MeV, and that the 1.428-MeV line coincides with beta rays of more than 0.8 MeV. These results, together with the intensities quoted in Table I, show that these gamma-ray energies represent levels in the decay scheme of the daughter nucleus Zn^{69}. This confirms the conclusions drawn from the NaI(Tl)-sum spectrum. The β-γ coincidence spectra also suggest that the 0.5952-MeV transition is related to low-energy beta decay and will therefore not represent a level.

All these conclusions are confirmed by γ-γ coincidence measurements. The measurements were made with two 3-in.$\times$3-in. NaI(Tl) counters, placed parallel and close to each other, sometimes with a 1-cm-thick lead shield between them. The source was placed close to the front faces and equidistant from the two counters. In this way most of the possible coincidences from annihilation radiation were avoided. Because the counting rates were small, the influence of accidental coincidences were negligible.

Several gamma-gamma coincidence spectra are shown in Fig. 4. Sometimes two neighboring channels have been averaged in order to obtain some smoothing of the curves. The many 0.511-MeV coincidences are due to annihilation escape following the event in which a high-energy gamma-ray quantum interacts with one of the counters. The 1.007- and 0.83-MeV gated spectra were measured in the sequence: 2.5-min irradiation, 0.5-min counting (aimed at recognizing any presence of short-

[4] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Science, Washington, D. C.), NRC 61-3-148. Beta-Disintegration Energy Charts, prepared by F. Everling, N. B. Grove, and R. van Lieshout.

lived Cu^{68}), 2.5-min counting, 2.5-min wait, and again 2.5-min counting; for the other spectra shown in Fig. 4, the 0.5-min counting period has been omitted. Figure 4 shows the difference between the first and the second 2.5-min counting periods. This procedure again effectively eliminates the influence of any long-lived component.

The interpretation of these spectra is aided by several suggestions from Fig. 1 for possible cascades with crossovers. Directly confirmed are: 1.825 MeV $\leftrightarrow$ 0.834 +0.992 MeV, 1.428 MeV $\leftrightarrow$ 0.8975+0.5307 MeV $\leftrightarrow$ 0.8340+0.5952 MeV, and 1.1795 MeV $\leftrightarrow$ 0.6490+0.5307 MeV. Other coincidences must be due to gate impurities like 1.495-MeV coincidences with 0.5307 MeV and 1.076-MeV coincidences with 1.590 from Cu^{68} [Fig. 4(a)].

VI. ADDITIONAL MEASUREMENTS

a. Internal Conversion

Because of the low atomic number and the relatively high energy of the Zn^{69} gamma-ray transitions, it was not expected that internal conversion could be easily observed. Two methods for observing this decay mode were tried. First, the electron spectrum of the powder source was scanned with a 2-mm-thick lithium-drifted silicon detector at dry-ice temperature. No evidence for conversion was found, though several hours after irradiation the conversion of the 0.439-MeV, 14-h Zn^{69} line ($\alpha=0.06$) became visible. Secondly, a search for x rays has been made with a Reuter-Stokes (RSG 30A) proportional counter, having a 1.5-keV resolution at an energy of 6 keV. For this purpose the powder source was placed behind a 4-mm-thick Be plate in order to stop the beta rays. Very weak, short-lived Zn x radiation was present, but this can be explained by interaction from the beta rays with the Zn powder sample rather than from internal conversion electrons. After several hours of counting the proportional counter also showed the x ray due to the 0.439-MeV, 14-h Zn^{69} line. From the x-ray data it is deduced that the ratio of the number of K-conversion events to the number of 1.0065-MeV gamma quanta must be less than 0.20. This limit is, however, too large to be conclusive for the multipolarity of the reported Zn^{69} gamma transitions.

b. Feeding of the 0.439-MeV Isomeric Transition

The allowed character of the beta-ray decay modes suggests that no large spin changes are involved in the decay of Cu^{69}. Probably almost all of the 14-h 0.439-MeV transitions were induced in the samples from $Zn^{70}(\gamma,n)$ during activation and not by feeding from Cu^{69}. Furthermore, all of the intense gamma-ray lines in the Cu^{69} decay have been placed in a decay scheme, to be discussed in Sec. VII, without using the 0.439-MeV level. Nevertheless, a search was made for possible feeding of this 0.439-MeV level by performing a fast chemical Cu-Zn separation within 1 min after irradiation of some Zn^{70} powder. In the Cu extract no 0.439-MeV, 14-h line was found. However, the weakness of the source did not allow accurate measurement. The results did not yield a very meaningful number for the upper limit of created 0.439-MeV excitations, a number which was less than twice the number of Cu^{69} nuclei decaying to the 1.0065-MeV excited state from the same Cu extract.

VII. DECAY SCHEME AND DISCUSSION

The assignment of the reported new activity to Cu^{69} can be based on several arguments. First of all, the cross section for its production by $Zn^{70}(\gamma,p)$ is of the expected order of magnitude. It compares well[5] with the production in the same sample of Zn^{69} by $Zn^{70}(\gamma,n)$, of Cu^{68} by $Zn^{70}(\gamma,np)$ and of Cu^{66} by $Zn^{67}(\gamma,p)$. The chemical separation described in Sec. VIb showed that the isotope is a Cu isotope. Furthermore, the observed total disintegration energy of 2.48 MeV is in accordance with expectations (Sec. IV). The assignment to Cu^{69} can also be concluded by way of exclusion, since there is no known isotope with the reported beta- and gamma-ray activity, while all other observed activities could be identified.

The gamma-ray transitions and their main features have been summarized in Table I. It can be assumed that all decay modes are due to beta disintegration of the ground state of Cu^{69}, since no evidence has been found for existence of any isomeric state in the parent nucleus. In Sec. IV it has been shown that the beta decay to the ground state of Zn^{69} is dominant. In the analysis of the complex gamma-ray spectrum of the remaining decay modes, it will be assumed (1) that there exists no significant internal conversion, and (2) that the 0.439-MeV level in Zn^{69} is not fed by Cu^{69} decay. Attempts to verify this were presented in Sec. VI, but yielded only very high upper limits.

From the gamma-ray intensities (Table I), from the evidence for summing in the NaI(Tl) spectrum, and from the γ-γ and β-γ coincidence measurements, it can be concluded that the gamma-ray transitions of 0.5307, 0.8340, 1.0065, 1.1795, 1.428, 1.825, and 2.026 MeV are transitions to the ground state and establish levels for Zn^{69}. Transitions coincident with 0.5307 and 0.8340 MeV are reported in Sec. V (Fig. 4) and are shown in the decay scheme of Fig. 5. These coincident transitions are much less intense than the 0.5307- and 0.8340-MeV transitions, so that there has to be additional population of these levels by direct beta decay.

The only lines not yet considered are the weak ones at 0.084, 0.110, 0.173, 2.17, and 2.4 MeV. The 2.17- and 2.4-MeV lines probably represent levels decaying to the ground state, since they do not evidently show summing (see Sec. III). Because of the perfect energy fit, the 0.173-MeV line can be placed between the 1.0065- and 0.8340-MeV levels. The 0.084-MeV and the 0.110-

[5] B. I. Goryachev, At. Energy Rev. 2, 71 (1964).

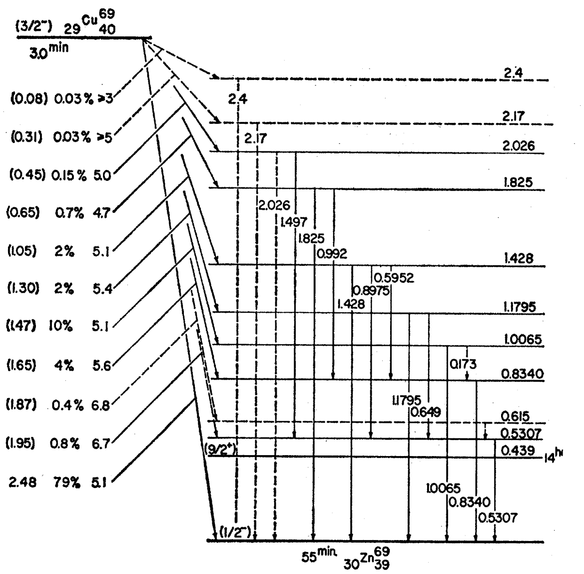

FIG. 5. Decay scheme of Cu^{69}.

MeV transitions are thus left as lines for which the assignment in the decay scheme remains questionable. The 0.084-MeV line, weak but distinct in the Ge(Li) spectrum, is strong in the 0.53-MeV gated coincidence spectrum [Fig. 4(d)]. However, there will be some interference of spurious x rays from lead shielding. In this coincidence spectrum the line is definitely of short half-life and decreases in intensity when the gate is shifted to neighboring energies by 10 to 20 keV. In any case the 0.084-MeV line needs another Zn^{69} level, since no energy fit exists in the present scheme. We tentatively assigned it to a level at 0.615 MeV which decays to the level at 0.5307 MeV.

During attempts to locate the still weaker transition of 0.110 MeV, we found γ-γ coincidences between 0.110- and $\sim$0.33-MeV pulses. The existence of a transition of 0.33 MeV could not be confirmed with the Ge(Li) detector because of the strong annihilation radiation and its Compton distribution. Although the 0.110- and 0.33-MeV transitions are considered tentative and not placed in the decay scheme, it seems worth noting that the 0.33-, 0.110-, and 0.173-MeV energies add within error limits to the 0.615-MeV level, which is itself a tentative level.

The present data are thus sufficient to establish the main features of the decay scheme (Fig. 5), though it seems probable that improved resolution, plus increased source strength or better detection efficiency, will reveal further structure.

The percentage P of beta decay to the ground state can now be deduced from the value $R=0.10\pm0.02$ given in Sec. IV. Using the gamma intensities given in Table I and the decay scheme thus far established, we derive $P=(79\pm5)\%$. The intensities of the other beta branches follow from this percentage and the known gamma-ray intensities and are inserted in Fig. 5 together with the logft values.

The daughter nucleus Zn^{69} is characterized by two $2p_{3/2}$ protons outside the closed $1f_{7/2}$ shell and one odd neutron in the $2p_{1/2}$ shell. Its ground state is probably $\frac{1}{2}^-$ as suggested also by $[d,p(\theta)]$-reaction data with stable Zn^{68} from Eby[6] and from Shull and Elwyn.[7] The allowed logft value of the 2.48-MeV beta decay leads to a $\frac{1}{2}^-$ or $\frac{3}{2}^-$ assignment for the Cu^{69} ground state, whereas the shell model and the similarity with the other odd Cu nuclides strongly suggest a further restriction of this assignment to $\frac{3}{2}^-$. Most of the other logft values are also less than 6.0, so that probably a negative parity can be assigned to all the levels obtained, except perhaps to the 0.5307-MeV and to the tentative 0.615-MeV level.

The information obtained establishes the major part of the decay scheme, but remains insufficient to make definite spin assignments. It is unfortunate that at the present time γ-γ angular-correlation measurements are not feasible because of the low counting rate. It may become possible to obtain useful angular correlations for the coincident transitions of 0.5307 and 0.649 MeV and for those of 0.8340 and 0.5952 MeV, if in the future stronger sources and bigger Ge(Li) detectors of improved resolution can be employed. From the present data we can, however, say that the unknown spin values are probably restricted to $\frac{1}{2}$, $\frac{3}{2}$, and $\frac{5}{2}$, because of the feeding of the levels by allowed beta decay.

It would be of interest to compare the remarkably large number of levels found for Zn^{69} with level structure of neighboring nuclei. One systematic feature is the well-known occurrence of isomerism for nucleon numbers between 39 and 49, due to the spin difference of 4 for transitions from the $g_{9/2}$ to the $p_{1/2}$ level. This is seen in the 0.439-MeV M_4 transition in Zn^{69}, which occurs in a similar way in Zn^{71} and in Ge^{71}. But except for a 0.175-MeV $\frac{5}{2}^-$ level in Ge^{71}, no further levels have been reported for these isotopes.

ACKNOWLEDGMENTS

Two of the authors (J. V. K. and R. J. H.) wish to acknowledge the pleasant hospitality of the Physics Department of the Iowa State University. We are much indebted to Professor E. N. Hatch for stimulation and for discussions during the course of the investigation. During various stages of the measurements the assistance of R. G. Clark, D. F. Boneau, and L. M. Taff was very helpful. We wish to thank Professor D. S. Martin and L. E. Shiers for their efforts in performing a fast chemical separation. We also thank Dr. S. A. Williams for discussions concerning the decay scheme.

APPENDIX ON THE DECAY OF Cu^{68}

Cu^{68}, the (γ,np) reaction product from Zn^{70}, is an important interfering activity with a half-life of 30 sec.

[6] F. S. Eby, Phys. Rev. **96**, 1355 (1954).

[7] F. B. Shull and A. J. Elwyn, Phys. Rev. **112**, 1667 (1958).

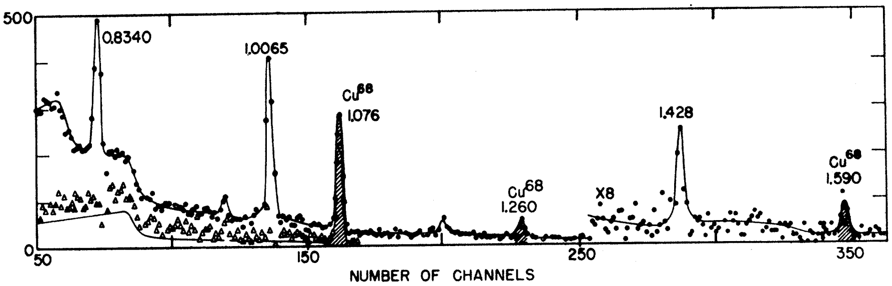

FIG. 6. Ge(Li) spectrum. Upper curve (•): compound spectrum with enhanced 0.5-min Cu^{68}; (Δ): result after subtraction of Cu^{69} below 1.1 MeV; lower curve: Compton distribution of 1.076-MeV transition.

It shows up in Fig. 1 and its effect should be subtracted from the upper curve in Fig. $2(b)_1$. This activity in the metal-bead sample has been enhanced by employing shorter irradiation and counting times. Figure 6 is the accumulated result of 20 runs with the following sequence: 30-sec synchrotron irradiation, 30-sec count in memory 1 (started ~15 sec after irradiation), 30-sec count in memory 2 and 60-sec count in memory 3. The upper curve shows a compound spectrum from memory 1 of Cu^{68}, Cu^{69} and a very small amount of longer-lived activities for energies between 0.75 and 1.8 MeV. From this spectrum the Cu^{69} component is subtracted in such a way that both peaks at 0.8340 and 1.0065 MeV disappear. In a similar way the NaI(Tl) spectrum of Fig. $2(c)_2$ has been obtained.

The level scheme for the daughter nucleus is relatively well known[8] from the decay of Ga^{68}, an isotope which is relatively easy to produce. The decay of Cu^{68} has been reported by Bakhru and Mukherjee,[9] who produced the activity by (n,p) reaction with stable Zn^{68}. They reported the 2.32-MeV sum peak only tentatively, but concluded that there is strong summing of 1.08+0.81 MeV to 1.88 MeV. They did not report evidence for a ~1.58-MeV transition, known from the Ga^{68} decay. However, these conclusions are not confirmed by the present data. The present spectra show very distinctly a 2.32-MeV peak as 1.260+1.076-MeV summing with the NaI(Tl) spectrometer and probably as a single crossover transition with the Ge(Li) spectrometer (see Fig. 1). Figure 6 shows also the 1.590-MeV transition known from Ga^{68} decay. On the other hand, Fig. $2(c)_2$ shows little evidence for a ~1.89-MeV sum-peak, and Fig. 6 none for an ~0.81-MeV line. However, the statistics are poor, so that actually a weak peak around 0.81 MeV might have escaped detection. In that case, the peak will be superimposed on the Compton distribution of the 1.076-MeV line. The slope of this Compton distribution, drawn as the lower curve of Fig. 6, was measured by observing the Compton distribution of the close lying 1.064-MeV line of Bi^{207}. The upper limit for the relative intensity of any peak close to 0.81 MeV, is estimated to be 8% of the 1.076-MeV line. A similar limit is obtained from analysis of summing in Fig. $2(c)_2$. This spectrum also has indications for peaks at 1.74 and 2.05 MeV not reported from the Ga^{68} decay. The relative intensities of these lines, as estimated from the Ge(Li) and NaI(Tl) spectra, are given in Table II.

TABLE II. Estimated intensities.

MeV	Intensity	MeV	Intensity
~0.81	≲8	1.74±0.02	≤2
1.076±0.001	100	2.05±0.02	≤2
1.260±0.003	15	2.32±0.01	~1
1.590±0.002	4		

More tentative peaking at 0.85, 1.38, and 1.90 MeV is indicated with a question mark in Fig. $2(c)_2$. The evidence for these lines depends somewhat on the amount of subtraction for residual Cu^{69} activity from the curve $2(c)_1$ and on a slight systematic shift in pulse amplification caused by a change of the counting rate during the various counting periods. Because of their tentative assignments, no attempts have been made for assigning these possibly new transition modes to levels in Zn^{68}.

[8] H. W. Taylor and R. McPherson, Can. J. Phys. **41**, 554 (1963), and references mentioned therein.

[9] H. Bakhru and S. K. Mukherjee, Nucl. Phys. **52**, 125 (1964).