less than one percent. In the lower-resistivity ranges where impurity scattering becomes effective, the accuracy of the determination of the number of impurities is no greater than the degree of purity obtained at present.

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K-Auger Electrons, Positrons, and Conversion Electrons of Zn^{65} Above 5 kev

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The momentum distributions of *K*-Auger electrons, positrons, and conversion electrons of Zn^{65} have been measured in a magnetic lens spectrometer, with very thin sources and counter windows. The positron Fermi plot was found to be linear from the end point of 325 ± 3 kev to about 50 kev. The positron decay is simple, contrary to some previously published results. From the observed intensities of *K*-Auger electrons, positrons, and conversion electrons, and values of capture branching ratio, fluorescence yield, and *L* to *K* capture ratios taken from the literature, the intensity ratios of the various spectral components have been obtained. The resulting conversion coefficient, $\alpha=(2.56\pm0.29)\times10^{-4}$, agrees with other experimental determinations and strongly suggests an *E*2 transition. The observed ratio of *K* capture to the ground state to positrons, 28.0 ± 3.2, is in satisfactory agreement with the recently calculated theoretical value of 29.0 for an allowed transition. This agreement, in view of the high *ft* value, establishes the *l*-forbidden character of the transition.

I. INTRODUCTION

IN 1938 Perrier, Santangelo, and Segrè[1] reported a 245-day activity in zinc, separated from copper filings from a deflecting plate which had been subject to strong deuteron and neutron bombardment in the Berkeley cyclotron. A few months later Barnes and Valley[2] reported such an activity (7 months) in copper parts of a cyclotron in which only protons had been accelerated, and found both electrons and positrons to be emitted. Sagane[3] produced this activity by Cu(d,n) and Zn(n,γ) and assigned it to Zn^{65}. Livingood and Seaborg[4] also produced this activity by Cu(d,n) and Zn(n,γ) and in addition produced it by Zn(d,p). On the basis of the latter reaction they confirmed the assignment to Zn^{65}, and they measured the half-life as 250 ± 5 days.

On the basis of cloud-chamber measurements Watase, Itoh, and Takeda[5] reported the presence of gamma rays of 0.45, 0.65, and 1.0 Mev. In magnetic spectrometers Deutsch, Roberts, and Elliott,[6] and Mandeville and Fulbright[7] found only one gamma ray, of energy 1.14 Mev. Jensen, Laslett, and Pratt[8] found the energy of this gamma ray to be 1.118 Mev and Mann, Rankin, and Daykin[9] reported it as 1.114 ± 0.005 Mev. The conversion coefficient of this 1.11-Mev gamma ray was measured in a magnetic spectrometer by Waggoner, Moon, and Roberts[10] and, more recently, by Strucken and Weber.[11] They reported values of $(2.28\pm0.26)\times10^{-4}$ and 2.5×10^{-4}, respectively.

The positron end-point energy has been measured with magnetic spectrometers by Peacock, Jones, and Overman,[12] by Mann, Rankin, and Daykin,[9] and by Yuasa.[13,14] They obtained 0.32 Mev, 0.325 ± 0.002 Mev, and 0.32 Mev, respectively. Shoupp[15] has measured the (p,n) threshold of Cu^{65} and assigned a positron end-point energy of 355 ± 20 kev, which becomes 327 ± 20 kev on the basis of the present value of the neutron-proton mass difference.[16]

Considerable disagreement exists on the shape of the

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[1] Perrier, Santangelo, and Segrè, Phys. Rev. **53**, 104 (1938).
[2] J. W. Barnes and G. W. Valley, Phys. Rev. **53**, 946 (1938).
[3] R. Sagane, Phys. Rev. **55**, 31 (1939).
[4] J. J. Livingood and G. T. Seaborg, Phys. Rev. **55**, 457 (1939).
[5] Watase, Itoh, and Takeda, Proc. Phys. Math. Soc. Japan **22**, 90 (1940).
[6] Deutsch, Roberts, and Elliott, Phys. Rev. **61**, 389 (1942).
[7] C. E. Mandeville and H. W. Fulbright, Phys. Rev. **64**, 265 (1943).
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[9] Mann, Rankin, and Daykin, Phys. Rev. **76**, 1719 (1949).
[10] Waggoner, Moon, and Roberts, Phys. Rev. **80**, 420 (1950).
[11] E. F. Strucken and A. H. Weber, Phys. Rev. **91**, 484 (1953).
[12] Peacock, Jones, and Overman, Plutonium Project Report Mon N-432, 56 (1947).
[13] T. Yuasa, Compt. rend. **235**, 366 (1952).
[14] T. Yuasa, Physica **18**, 1267 (1952).
[15] Shoupp, Jennings, and Jones, Phys. Rev. **73**, 421 (1948).
[16] R. Bouchez, Physica **18**, 1171 (1952).

TABLE I. Intensity ratios as measured by various observers.

γ/β^+	Total K capture/β^+	References	K_2/K_1	References
20.4[a]	41	Good, Peacock[b] 1946	54/46	Good, Peacock[b] 1946
16	32	Zumwalt[c] 1947	56/44	Furberg[d] 1951
19[a]	39	Major[e, f] 1951	55.2/44.8	Major[e, f] 1951
65±5[a]	132±10	Griffiths[g] 1951	50/50	Peacock (see Griffiths,[g] unpublished) 1951
64±12	130±25[a]	Townsend[h] 1951		
38±4[a]	77±8	Bouchez, Perrin[i] 1952		
20±3	41±5[a]	Yuasa[j, k] 1952		

[a] Indicates this value was measured. The value of the other ratio was calculated in each case from a value of 44.9 percent of the K captures going to the excited state and the assumption that L capture to the excited state is 0.10 times as probable as K capture to the excited state. [b] See reference 18. [c] See reference 19. [d] See reference 20. [e] See reference 21. [f] See reference 22. [g] See reference 23. [h] See reference 24. [i] See reference 16. [j] See reference 13. [k] See reference 14.

positron spectrum. Mann, Rankin, and Daykin,[9] using a 25-mg cm^{-2} source, obtained a linear Fermi plot down to 150 kev. Yuasa[13,14] used a 4-mg cm^{-2} source and reported two positron groups, of energies 320 kev and 150 kev, of roughly equal intensities. Cohn and Kurbatov[17] reported coincidences of positrons with 210-kev gamma rays and 200-kev electrons such as would be expected from a complex positron spectrum. The 210-kev gamma rays were also reported by Bouchez.[16]

The relative intensities of the 1.11-Mev gamma radiation, the positrons, and the decays by K capture have been studied experimentally in a number of ways. γ-K x-ray coincidences give the K-capture branching ratio K_2/K_1, where K_2 represents the rate of capture to the ground state of Cu^{65}, independent of fluorescence yield uncertainties. The three *published* values are shown in Table I and are in excellent agreement. Their average, 44.9±0.6 percent K captures to the excited state, will be used as the correct value in the remainder of this paper. The other ratios, γ/β^+ and (Total K capture)/β^+, have each been measured since 1945 by several observers, as shown in Table I.[13,14,16,18–24] The ratio, denoted by the superscript a, was directly measured in each case except Zumwalt's, and the value of the other ratio has been computed by use of the above branching ratio and by an allowance of 10 percent L capture to the excited state. The wide spread of values is apparent.

Thus, although strong K capture, 1.11-Mev gamma radiation, and weak 325-kev positrons are certainly present, many features of the decay scheme of Zn^{65} remain in doubt. The shape of the 325-kev positron spectrum has never been measured with a very thin source. There is still some question about additional low-energy gamma rays, and the relative intensity of the positrons as measured by different observers varies by more than a factor of four. It was therefore felt that an accurate measurement of the shape of the positron spectrum and of the relative intensities of the K-Auger electrons, the positrons, and the conversion electrons with high specific activity sources in a lens spectrometer would clarify many of these points. This paper will present the results of such a study.

[17] R. A. Cohn and J. D. Kurbatov, Phys. Rev. **78**, 318 (1950).
[18] W. M. Good and W. C. Peacock, Phys. Rev. **69**, 680 (1946).
[19] L. R. Zumwalt, Plutonium Project Report Mon N-432, 54 (1947).
[20] S. E. Furberg, Nature **168**, 1005 (1951).
[21] J. K. Major, Compt. rend. **233**, 947 (1951).
[22] J. K. Major, Phys. Rev. **86**, 631 (1952).
[23] G. M. Griffiths, Phys. Rev. **83**, 852 (1951).
[24] I. Townsend, Phys. Rev. **81**, 297 (1951).

II. EXPERIMENTAL METHODS

A. Introduction

The spectrometer has already been described elsewhere.[25] It is a lens type, with approximately 1.5 percent transmission, and has a resolution of approximately 2.5 percent to 3.5 percent, depending upon source size and baffle positions. This instrument was designed for accurate relative intensity measurements at low energies, for which purpose the earth's magnetic field is neutralized to within 0.1 percent by a special set of coils.[26] The instrument had previously been used for measurements down to 20 kev. The present measurement of the intensity of the 7-kev K-Auger electrons of Cu^{65} was the first use of the instrument in the 5-to 10-kev range so that it was necessary to investigate carefully its performance at these very low energies.

B. Sources

An accurate measurement of the momentum distribution of positrons, which are of very weak intensity, required material of rather high specific activity. An even stronger requirement of this type was imposed by the very low energies of the Auger electrons. Zn^{65} with a quoted specific activity of 10 000 mC g^{-1} was obtained from Oak Ridge, having been produced by deuteron bombardment of copper according to a technique developed by Maletskos, Backofen, and Irvine.[27] In order to insure uniform distribution of the source material over the desired area, the sources were prepared by vacuum evaporation of zinc chloride. A drop of this solution was placed on a tantalum filament and dried. The filament and a source backing were then placed in a small bell jar which was evacuated by an oil diffusion pump, and the filament was heated to a red heat for a second or two to evaporate the zinc chloride. Radioautographs of the sources showed a satisfactory uniformity of distribution of the source material. Source backings of 140 μg cm^{-2} Al were used for the positron and conversion electron measurements

[25] Broyles, Thomas, and Haynes, Phys. Rev. **89**, 715 (1953).
[26] S. K. Haynes and J. W. Wedding, Rev. Sci. Instr. **22**, 97 (1951).
[27] Maletskos, Backofen, and Irvine, J. Chem. Phys. **19**, 796 (1951).

and were tried for the K-Auger work. At the very low Auger energies there was appreciable backscattering from the foil, so that 10 μg cm^{-2} Zapon backings were used for the sources with which the K-Auger data were taken. Prior to being used as a source backing each Zapon film was given a very thin coating of aluminum by vacuum evaporation in order to avoid electrostatic charging of the source. The sources were 8 mm in diameter, except that a 4-mm diameter source was used for measurement of the intensity ratios of the three Auger lines, which gave an instrumental resolution of 2.5 percent. The sources used in the K-Auger measurements should have been considerably less than 1 μg cm^{-2} in thickness, but it is believed they were actually somewhat thicker, as the Auger lines showed a small low-energy tail. Plassman and Scott[28] have measured the K Augers of nickel on a 5 μg cm^{-2} source and find no low-energy tail, within intensity limits about equal to the size of the tail we observed in copper. The strong source used for positrons and conversion electrons had a calculated thickness of 5 μg cm^{-2} and broadened the Auger lines somewhat. Presumably it was also somewhat thicker since it was barely visible. It was not feasible to use this source to measure the Auger intensities, both because of the poor line shape and because of the very high counting rate of the Auger electrons.

C. Windows

A Zapon counter window of approximately 200 μg cm^{-2} was used for the measurement of the conversion electrons and all but the lowest energy portion of the positron spectrum; the intensity comparisons were made on the basis of these measurements, with the low-energy portion of the positron spectrum reconstructed on the basis of a linear Fermi plot fitted to the higher energy portion of the spectrum. This represented only a very small intensity correction. Because the 200-μg cm^{-2} window was expected to absorb some of the lower energy positrons, the positron spectrum was also measured with a 20-μg cm^{-2} counter window made from collodion. The K-Auger measurements were made with 6-μg cm^{-2} collodion counter windows. The thinner windows were mounted on Lektromesh which had an open area of the order of 30 percent and reduced the counting rate accordingly.

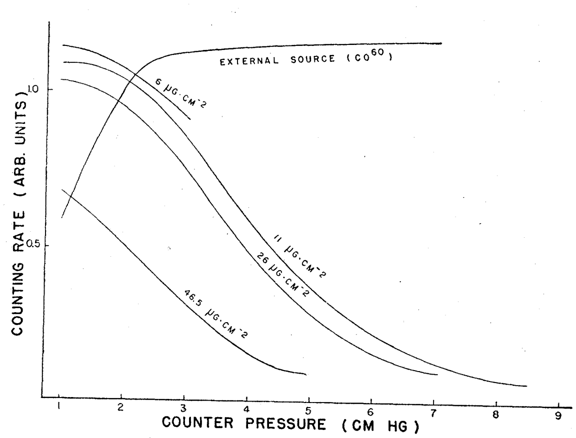

FIG. 1. Counting rate at 7 kev as a function of counter pressure at various counter window thicknesses.

[28] E. Plassman and F. R. Scott, Phys. Rev. 84, 156 (1951).

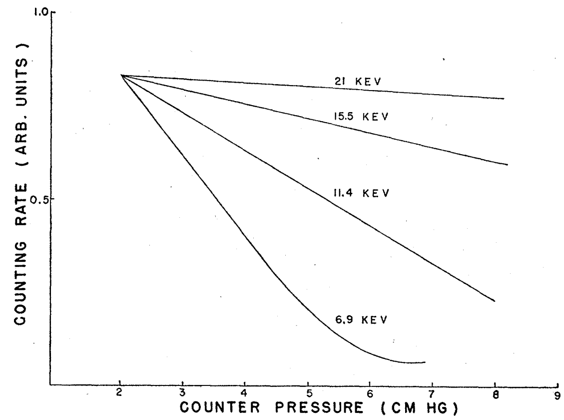

FIG. 2. Counting rate at various energies as a function of counter pressure, for a window thickness of 46 μg cm^{-2}. The curves were normalized to the same counting rate at 2-cm pressure.

D. Spectrometer Characteristics at Very Low Energy

The current control circuits and the coils for neutralizing the earth's field were found to function very satisfactorily down to at least 5 kev, and there was no appreciable scattering of electrons from residual gas in the spectrometer chamber when the vacuum was better than 10^{-5} mm Hg, a value which is fairly readily attained when 6-μg cm^{-2} windows are used. There was an almost negligible absorption of 7-kev electrons by a 6-μg cm^{-2} counter window. The counter, however, showed a counting rate at very low energies which decreased as the pressure of the argon-ethylene counter gas was increased. It was thus necessary to correct for the resultant loss in counting rate, most of which arose from absorption in the gaseous dead space of the counter. For this purpose the counting rate at 7 kev was measured as a function of counter pressure at different window thicknesses, as shown in Fig. 1. Figure 2 shows the variation of counting rate with counter pressure for a 46-μg cm^{-2} window at several energies. The dead-space absorption decreases as the electron energy increases, and is negligible above about 20 kev for the range of counter pressures which are normally used.

Measurements of the K-Auger spectrum with 3-cm Hg counter pressure revealed a statistical spread of the data greater than was to be expected from counting statistics alone, whereas the statistical spread of data obtained with 2-cm Hg counter pressure was normal. This difference presumably arose from the small variations in counter pressure resulting from leaking of the counter windows and imperfect pressure regulation by the cartesian manostat. Small fluctuations about 3 cm Hg would be expected to produce larger variations in counting rate than fluctuations of pressure in the 2-cm Hg range, for the curves of Fig. 1 show a steeper slope at the higher pressure. The K-Auger intensity measurements which were compared with the positron and conversion electron intensities were made with 2-cm Hg counter pressure, and these data were corrected to 100 percent transmission on the basis of the curves of Fig. 1. This involved increasing the observed intensity by 15 ± 4 percent. The relative intensities of the three Auger lines were later measured with 1-cm Hg counter pressure and with a different source and a different baffle arrangement.

A broad group of L-Auger electrons was observed at 700 ev, with a leaky 3-μg cm^{-2} window and 0.4-cm Hg counter pressure, which is a lower limit for satisfactory counting. Below this pressure pulses were followed by

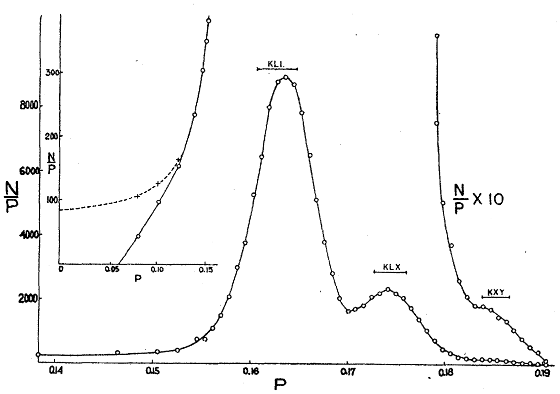

FIG. 3. K-Auger spectrum of copper with a 3.5 percent instrumental resolution. The circles show experimental points. The crosses on the low-energy tail show counting rate corrected for absorption of electrons between the spectrometer chamber and the sensitive volume of the counter.

damped oscillations and the counter operation was erratic. No reliable intensity measurements could be made with the 3-μg cm^{-2} window because of poor vacuum in the spectrometer.

E. Normalization

In order to compare the intensity of the K-Auger electrons with the positrons and conversion electrons it was necessary to correct for the difference in source strengths and window transmissions used in these measurements. The source strengths were compared within a probable error of 1 percent by a count of each source with a laboratory end-window counter at the same geometry. This comparison was checked by a count of the weaker source in the spectrometer at one point on the positron spectrum. Several hours of counting confirmed the counting comparison within a probable error of 7 percent.

The transmission of the Lektromesh support used with the thin windows was measured by a count of 189-kev electrons from a Cs^{137} source with both thin supported and thick unsupported windows, 6-cm Hg counter pressure being used in each case.

The data were of course corrected for decay of the sources, on the basis of the 250-day half-life measurement of Livingood and Seaborg.[4]

III. EXPERIMENTAL RESULTS

A. Auger Electrons

The observed K-Auger electron spectrum is shown in Fig. 3. The low-energy tail on the KLL-Auger line was unexpected in view of the high specific activity of the source material which was quoted by Oak Ridge. A series of experiments was performed to determine whether this low-energy tail might be the result of some effect other than self-absorption of the source. That the tail was not the result of backscattering was indicated by the fact that it remained unchanged when the backing was reduced from 30 μg cm^{-2} to 10 μg cm^{-2}. A 2-mg cm^{-2} cellophane absorber placed just in front of the source in the spectrometer eliminated the low-energy tail as well as the main part of the spectrum, showing that this low-energy distribution resulted from low-energy electrons from the source rather than from electrons knocked out of the spectrometer walls by gamma- or x-rays from the source. Use of paddle-wheel baffles established the negative charge of the low-energy particles, showing they did not result from the positron spectrum. Runs were made with various anti-scattering baffle arrangements and with different focusing baffle arrangements with the result that the low-energy electrons remained in the same proportion to the rest of the Auger spectrum. That these electrons were truly electrons, which had left the source with momenta proportional to the focusing currents at which they were observed, rather than scattered 7-kev electrons was further substantiated by examinations of the spectrum with thick windows. Windows which reduced the 7-kev electron intensity by 50 percent reduced by 85 percent the intensity of electrons observed at currents appropriate to 3.5-kev electrons. These experiments showed the low-energy tail to be the result of self-absorption; thus it was proper to consider the tail as part of the total Auger intensity.

The observed low-energy tail extended to about 1 kev, which represented the cut-off energy of the counter window. Thus it became necessary to make a rather large correction for absorption in the counter window and gaseous dead space. This correction has been made on the assumption that transmission of electrons into the sensitive volume of the counter is a function of the ratio of electron energy to window thickness, and the ratio of electron energy to counter pressure. That this assumption represents a valid first approximation was confirmed by a prediction, from these assumptions and the results of Fig. 2, of the shape of the transmission curves for 7-kev electrons and various window thicknesses, and a comparison of these with visual interpolations of the curves of Fig. 1. In Fig. 3 the measured intensities are indicated by circles; the crosses represent points that have been corrected for absorption. The corrections become very large below about 2 kev, so that one is forced to extrapolate the distribution to zero energy. Because of the rather large uncertainty involved in this process, an uncertainty has been assigned to the total Auger intensity equal to ± 50 percent of the total area added to the tail by the absorption correction.

The intensity ratios of the *KLL*-, *KLX*-, and *KXY*-Auger groups have been measured both from the results presented in Fig. 3 and from measurements made with a smaller source and different baffle spacing which gave better resolution. The following values were obtained:

$$KLL:KLX:KXY=1.00:0.292\pm 0.010:0.016\pm 0.002.$$

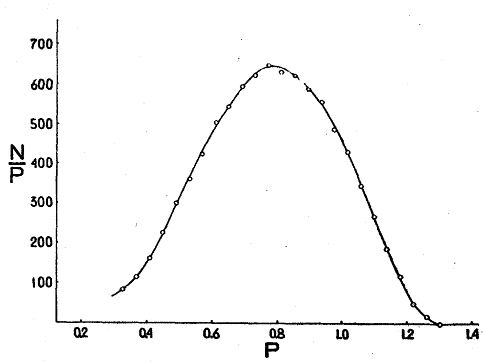

FIG. 4. Positron momentum distribution.

The indicated uncertainties were estimated on the basis of the necessary extrapolation of the low-energy sides of the *KLX* and *KXY* lines. The first of these ratios has been measured for a few other elements.[25] The present results are in satisfactory agreement with the trend established by the other results.

B. Positron Spectrum

Although the source was very thin, the high intensity of gamma rays relative to positrons resulted in a small contribution of Compton electrons over the range of the positron energies. In order to correct for this contribution to the counting rate from Compton electrons, these were measured with a set of paddle-wheel baffles introduced into the spectrometer so as to eliminate the positrons. This Compton distribution was then subtracted from the total distribution obtained without paddle-wheel baffles.

Correction for the distortion of the continuous positron spectrum which resulted from the finite instrumental resolution was made on the basis of formulas given by Owen and Primakoff.[29] The instrumental line shape was approximated by a Gaussian error function and the curvature of the spectrum was obtained from second-order finite difference equations applied to a reconstructed positron spectrum. The resulting distribution, which was taken from the 200-μg cm^{-2} data, is shown in Fig. 4.

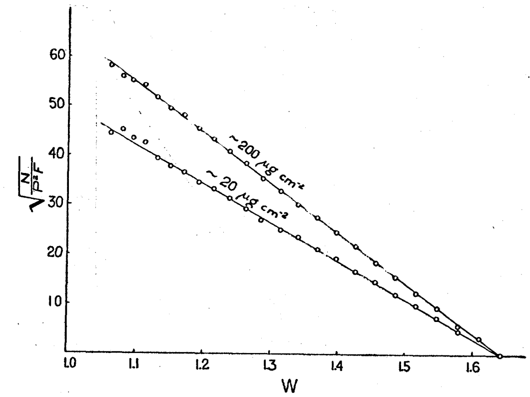

FIG. 5. Positron Fermi-Kurie plots, with screening corrections interpolated from Reitz's calculations by use of the approximate formula given in the NBS Tables for the Analysis of Beta Spectra (reference 30).

The Fermi plots of the 200-μg cm^{-2} and the 20-μg cm^{-2} positron data are shown in Fig. 5. The Fermi function was obtained by interpolation in the NBS tables,[30] using second and fourth order interpolation formulas. The positron screening correction was obtained from the approximate formulas given in these tables, with a screening potential of 2.5 kilovolts. The choice of this value was made after the results of these approximate formulas had been compared with the accurate screening corrections calculated by Reitz.[31] This comparison indicated that the approximate screening corrections used were accurate to within 6 percent over the entire range of energies shown in Fig. 5.

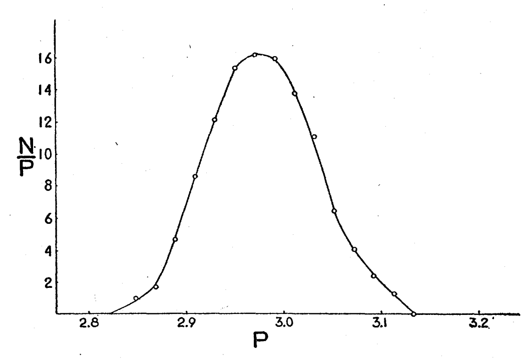

FIG. 6. Conversion line of the 1.11-Mev gamma ray. The line is somewhat wider than was expected on the basis of the instrumental resolution, suggesting $K/L<10$.

[29] G. E. Owen and H. Primakoff, Rev. Sci. Instr. **21**, 447 (1950).
[30] *Tables for the Analysis of Beta Spectra* (National Bureau of Standards, Washington, D. C., 1952).
[31] J. R. Reitz, Phys. Rev. **77**, 10 (1950).

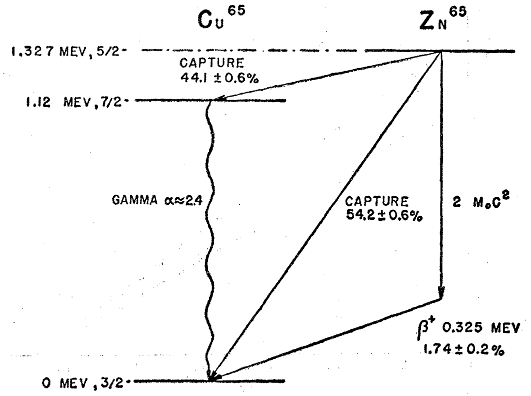

FIG. 7. Decay scheme of Zn^{65}. The spin of the Cu^{65} ground state has been measured. The spins of the other states and their like parities seem to be the only possibilities consistent with the experimental results given in this paper. The fact that the parities are odd depends only on shell theory. The values of log ft are 5.8 and 7.3 for the transitions to the excited and ground states, respectively, of Cu^{65}. The energy of the ground state of Zn^{65} should be 1.345, not 1.327 as shown in the figure.

C. Conversion Line

The only conversion line which was found was the well-known 1.11-Mev line, which is shown in Fig. 6. The observed width is somewhat greater than was expected on the basis of the instrumental resolution, and tends to favor a K/L conversion ratio of less than the theoretical value[32–34] of 10, in agreement with conclusions of Goldhaber and Sunyar.[35]

D. Intensity Ratios

The observed integrated intensity ratios of K-Auger electrons to positrons to conversion electrons were 10 270±590:361±3:2.345±0.047.

IV. INTERPRETATION

The linearity of the positron Fermi plot indicates the absence of an excited state at about 200 kev above the ground state of Cu^{65} and justifies the assumption of just two capture branches as shown in Fig. 7. From the value of the half-life (250 days), the K-capture branching ratio to the excited state (44.9±0.6 percent) which was previously discussed, and the known energies of the capture transitions 0.229 Mev and 1.345 Mev) approximate ft values were calculated from formulas given by Konopinski.[36] The value for capture to the excited state is clearly within the range of allowed transitions.[36,37] It is, therefore, clear that

(a) the parity of the excited state of Cu^{65} is the same as that of the ground state of Zn^{65}, and that

(b) Rose and Jackson's[38] value of 0.102 for L_I/K capture ratio for allowed transitions in Zn can be used for transitions to the excited state. In order to allow for M and higher orbital capture a value of 0.112 ± 0.01 was assumed for the ratio of outer orbit capture to K capture.

Using the measured ratio of conversion electrons to Auger electrons, the value of fluorescence yield for copper from Broyles *et al.*[25] of 0.44 ± 0.04, the K branching ratio discussed above, and the ratio of outer orbit capture to K capture to the excited state, one gets the following intensity ratios: K capture/conversion electrons $=7820\pm850$, K capture to excited state/conversion electrons $=3510\pm390$, Total capture to excited state/conversion electrons $=3903\pm430$, Conversion coefficient of the 1.11-Mev gamma ray $=(2.56\pm0.29)\times10^{-4}$.

The last value agrees within experimental error with previous measurements.[10,11] Table II shows the conversion coefficients expected for various transitions from $E1$ through $M3$. The values of K conversion coefficients are those of Rose *et al.*[39,40] The K/L conversion ratios are estimated from the empirical curves of Goldhaber and Sunyar.[35] Clearly the transition is predominantly $M1$ or $E2$ or a mixture of the two. Since all three experiments give values considerably higher than that predicted for $E2$ and much higher than that predicted for $M1$, the fraction of $M1$ present, if any, is probably small. When one considers that the radiative transition probability for $M1$ calculated according to Weisskopf[41] exceeds that for $E2$ by a factor of about 10^3, the high values of conversion coefficient offer strong evidence that $M1$ radiation must be excluded by spin change. One therefore concludes

(c) that the parity of the 1.11-Mev state of Cu^{65} is the same as that of the ground state,

(d) that the parity of the ground state of Zn^{65} is the same as that of the ground state of Cu^{65}

TABLE II. Experimental and theoretical conversion coefficients and radiative transition probabilities for various multipoles.

Experimental α	Multipole	α_K	α	Radiative transition probability
$(2.28\pm0.26)\times10^{-4}$	$E1$	1.2×10^{-4}		
	$M1$	1.69×10^{-4}	1.86×10^{-4}	4×10^{13} sec^{-1}
2.5×10^{-4}	$E2$	1.93×10^{-4}	2.12×10^{-4}	6×10^{10} sec^{-1}
$(2.56\pm0.29)\times10^{-4}$	$M2$	5.0×10^{-4}		
	$E3$	5.4×10^{-4}		
	$M3$	5.4×10^{-4}		1×10^{4} sec^{-1}

[32] I. S. Lowen and N. Tralli, Phys. Rev. **75**, 529 (1949).
[33] N. Tralli and I. S. Lowen, Phys. Rev. **76**, 154 (1949).
[34] M. H. Hebb and E. Nelson, Phys. Rev. **58**, 486 (1940).
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[36] E. J. Konopinski, Revs. Modern Phys. **15**, 209 (1943).
[37] Mayer, Moszkowski, and Nordheim, Revs. Modern Phys. **23**, 315 (1951).
[38] M. E. Rose and J. L. Jackson, Phys. Rev. **76**, 1540 (1949).
[39] Rose, Goertzel, and Perry, *K-Shell Internal Conversion Coefficients, Revised Tables* (Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1951), privately circulated.
[40] M. E. Rose *et al.*, Phys. Rev. **83**, 79 (1951).
[41] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952).

(e) that since Cu^{65} has a measured spin of 3/2,[42] the spin of the excited state is 7/2 and the gamma-ray transition is almost entirely $E2$.

There remains the possibility of a small admixture of $M3$, which is suggested by several lines of evidence. The conversion coefficient seems a little too high for pure $E2$. A little $M3$ would reduce the discrepancy between theory and experiment both by having a higher K conversion coefficient and also by having a lower K/L conversion ratio. The need for a lower K/L ratio is suggested by the fact that the conversion line shown in Fig. 6 when compared to a monoenergetic line seems too wide to be accounted for by the expected K/L ratio for an $E2$ transition. From a more general point of view, Goldhaber has shown that mixing sometimes occurs between $E1$ and $M2$, and between $E3$ and $M4$, so perhaps it might occur here in analogous fashion between $E2$ and $M3$ in spite of the apparent discrepancy in the calculated radiation transition probabilities.

From conclusion (d) above, it is evident that the transition to the ground state is either allowed or second forbidden. The approximate ft value, although considerably higher than allowed, is far too low for a second forbidden transition. The allowed character of the transition is also strongly supported by the linearity of the allowed Fermi-Kurie plot. One therefore concludes

(f) that the spin of the ground state of Zn^{65} must be 5/2 since only this spin could give allowed transitions to states of spins 3/2 and 7/2.

From the ratio of the area under the positron spectrum to that under the K-Auger lines, together with the other intensity ratios already computed, one obtains the intensity ratios: Total K capture/positrons $=50.8\pm5.8$; K capture to ground state/positrons $=28.0\pm3.2$.

The second of these ratios can be computed for an allowed transition independently of the nuclear matrix elements. Zweifel[43] has recently calculated a value of 29.0 for this ratio, which is in satisfactory agreement with our experimental value and substantiates the allowed character of the transition. This agreement is especially gratifying in view of the wide variation of previous experimental values shown in Table I.

Using for the ground state transition the ratio 0.112 ± 0.01 for (outer orbit capture)/(K capture), one finds for the fraction of disintegrations which go by positron emission 1.74 ± 0.2 percent. More precise ft values can now be computed and are given in Fig. 7, which shows the complete decay scheme.

The above conclusions have been obtained independently of any nuclear model. They are, however, in complete agreement with shell theory, which predicts odd parity for all three states. The ground state of Zn^{65}, the excited state of Cu^{65}, and the ground state of Cu^{65} are thus characterized in shell theory notation as $f_{5/2}, f_{7/2}$, and $p_{3/2}$, respectively. The larger than normally allowed ft value between ground states is explainable on a single particle shell model in terms of an l-forbidden transition. The orbital angular momentum changes by two units from 3 to 1 (f to p) while the total angular momentum changes by one unit (5/2 to 3/2). These assignments have already been suggested as the most probable by King[44] but other possibilities could not be excluded on the basis of the conflicting data available at the time.

These conclusions are also consistent with the experimental evidence concerning the beta decay of Ni^{65}. The ground state of this isotope is also $f_{5/2}$ according to shell theory, and the allowed and l-forbidden transitions which one would then expect to the 1.11-Mev excited state and ground state, respectively, of Cu^{65} are in agreement with the observed ft values. The spin and parity assignment of the 1.11-Mev state and the allowed ft values of the two softest beta groups in Ni^{65} [45] limit the 1.49-Mev state of Cu^{65} to either 7/2 odd or 5/2 odd. Either of these assignments corresponds to magnetic dipole 0.37-Mev radiation, whereas the 1.49-Mev radiation would be electric quadrupole (7/2) or magnetic dipole (5/2). On the basis of radiative transition probabilities calculated from the Weisskopf[41] formula and the observed comparable intensity of the 0.37-Mev and 1.49-Mev radiations,[45] it does not seem possible at present to distinguish between the two possible spins.

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[42] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).

[43] P. Zweifel (private communication). The details of these calculations will shortly be published in Mr. Zweifel's thesis, Duke University.

[44] R. W. King, *Beta-Decay Schemes and Nuclear Structure Assignments* (Washington University, St. Louis, 1952), privately circulated.

[45] K. Siegbahn and A. Ghosh, Phys. Rev. **76**, 307 (1949).