ON THE DECAY SCHEME OF ZN^{65}

by

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ABSTRACT

The radiation from Zn^{65} has been investigated in a thin lens beta ray spectrometer. A spiral baffle was used to discriminate between positrons and negatrons. Gamma ray energies of 1.12 and 1.4 mev have been measured as well as annihilation radiation of .51 mev. A positron end point at .32 mev has also been measured. Fairly intense internal conversion was found. A decay scheme has been proposed in which Zn^{65} decays by K-capture to a 1.4 mev excited state from which it proceeds to an intermediary state by emission of a gamma ray. The alternative positron emission is to the intermediary stage from which both paths descend to the ground state of Cu^{65} with the emission of a 1.1 mev gamma ray.

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ACKNOWLEDGEMENTS

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INTRODUCTION

Zn^{65} is an artificially radio-active isotope which has been investigated by various methods. This isotope has been produced by the following reactions:

$$Zn^{64}\ (d,p)\ Zn^{65}$$
$$Cu^{64}\ (d,2n)\ Zn^{65}$$
$$Cu^{65}\ (p,n)\ Zn^{65}$$
$$Zn^{64}\ (n,\gamma)\ Zn^{65}$$
$$Ga^{65}\ (\text{K-capture})\ Zn^{65}$$

A good deal of confusion attended the earlier investigation of the Cu-Zn-Ga compounds which were produced in the cyclotron by deuteron bombardment.

Livingood (1) reporting on one such element, suggests the possibility of a Zn isotope decaying through positron emission with a half-life of 12 hrs. This was undoubtedly one of the short life activities which is found in conjunction with Zn activities.

Perrier, Santangelo, and Segre (2) report, on their examination of the filings from the copper deflection plate of the Berkeley Cyclotron, the existence of a 245 day half-life activity. They do not attribute this to Zn^{65} since they quote Livingood's 12 hr. half-life activity as being Zn^{65}.

Barnes and Valley (3) report an activity produced in Cu by proton bombardment with a half-life of approximately

210 days. They suggest a positron and negatron emission in the ratio of 2:1. There is also a strong gamma radiation with a gamma to beta ratio of 60 to 1. The maximum energy of the Beta group is .7 mev as indicated by its absorption in aluminum.

Delsasso et al[4] report on a Cu^{65} (p,n) Zn^{65} decay with both positron and negatron activity in addition to strong gamma radiation. They suggest that the decay is

$$Zn^{65} \text{———} Cu^{65}$$

The fairly intense X radiation is attributed to both internal conversion of the gamma rays and K-capture with the negatrons due entirely to internal conversion.

Livingood and Seaborg[5], using the reaction

$$_{30}Zn^{64} + {}_{1}D^{2} \text{———} {}_{30}Zn^{65} + {}_{1}H^{1}$$

and $$_{29}Cu^{65} + {}_{1}H^{1} \text{———} {}_{30}Zn^{65} + {}_{0}n^{1}$$

and either $$_{29}Cu^{65} + {}_{1}D^{2} \text{———} {}_{30}Zn^{65} + {}_{0}2n^{1}$$

or $$_{29}Cu^{63} + {}_{1}D^{2} \text{———} {}_{30}Zn^{65} + \gamma$$

suggest the decay as both

$$_{30}Zn^{65} \text{———} {}_{29}Cu^{65} + \beta^{-}$$

and $_{30}Zn^{65} + e^{-} \text{———} {}_{29}Cu^{65}$ with a total half-life of 250 days. They point to the small number of particles as compared to gamma-rays as evidence of the existence of K-capture as an alternative to positron emission. From a consideration of positron and gamma-rays in equilibrium, the ionization produced by the positron rays should be approximately thirty times as great as that produced by the gamma radiation. Livingood and Seaborg find however, that the gamma-radiation produces the greater part of the ionization. This demonstrates the predominance of K-capture as the mode of decay. From absorption measurements in Pb, a high intensity gamma-ray with an energy of 1.0 mev together with an inappreciable amount of .5 mev annihilation radiation tends to confirm the low rate of positron emission to K-capture.

Alvarez[6] measured the absorption of the x-rays produced in this reaction. From a comparison of absorption in nickel and copper he deduced that the x-rays were the characteristic $Cu_{K\alpha}$ lines.

Sagane et al[7] using cloud chamber measurements have found end points for positron emission of .39 and .19 mev. These upper limits were calculated from K.U. plots.

Watase et al[8] however, found a single positron with an end point of .47 mev and fairly intense gamma radiation of 1.0, .65, and .45 mev in the ratios approximately 1:1:1.

Deutsch, Roberts and Elliott[9] report on Zn^{65} with a half-life of 250 days, and give a gamma-ray energy of 1.14 to better than 1%.

Good and Peacock[10], using a calibrated gamma-ray counter, measured X-gamma and positron-gamma coincidences. They found that 54% of K-capture occurs in the ground state and 46% in the 1.14 mev excited state; also that 2.2% of the transitions are by positron emission directly to the ground state of Cu^{64}.

W. C. Peacock[11] reports a positron end point of .320 mev.

Jensen, Laslett, and Pratt[12] using a high resolution beta-ray spectrometer, give a corrected value for the gamma-ray energy of 1.11 mev as measured from the photo-electrons ejected from a thin lead radiator.

Daykin[13], using the same thin lens spectrometer as the present investigator, found a gamma-ray energy of 1.11 mev as measured from the photo-electric peak in both lead and uranium and a positron end point of .32 mev. Since this work was done with a source of very low specific activity it was deemed attractive to repeat this investigation, using a stronger source with a view to a more detailed study of Zn^{65} activity.

APPARATUS AND EXPERIMENTAL TECHNIQUE

Spectrometer

The spectrometer used in this research is of the "thin lens" type introduced by Deutsch, Elliott and Evans[14]. A line diagram is shown in fig. 1 and a photograph of the complete assembly in fig. 2. The spectrometer consists of an evacuated brass tube 8" in diameter and 40" long, with a short

Figure 1 - Spectrometer

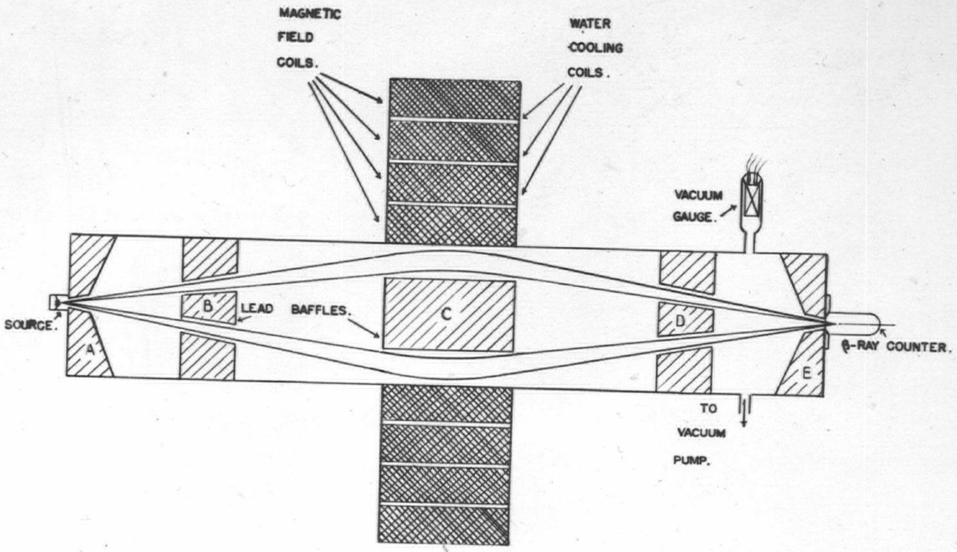
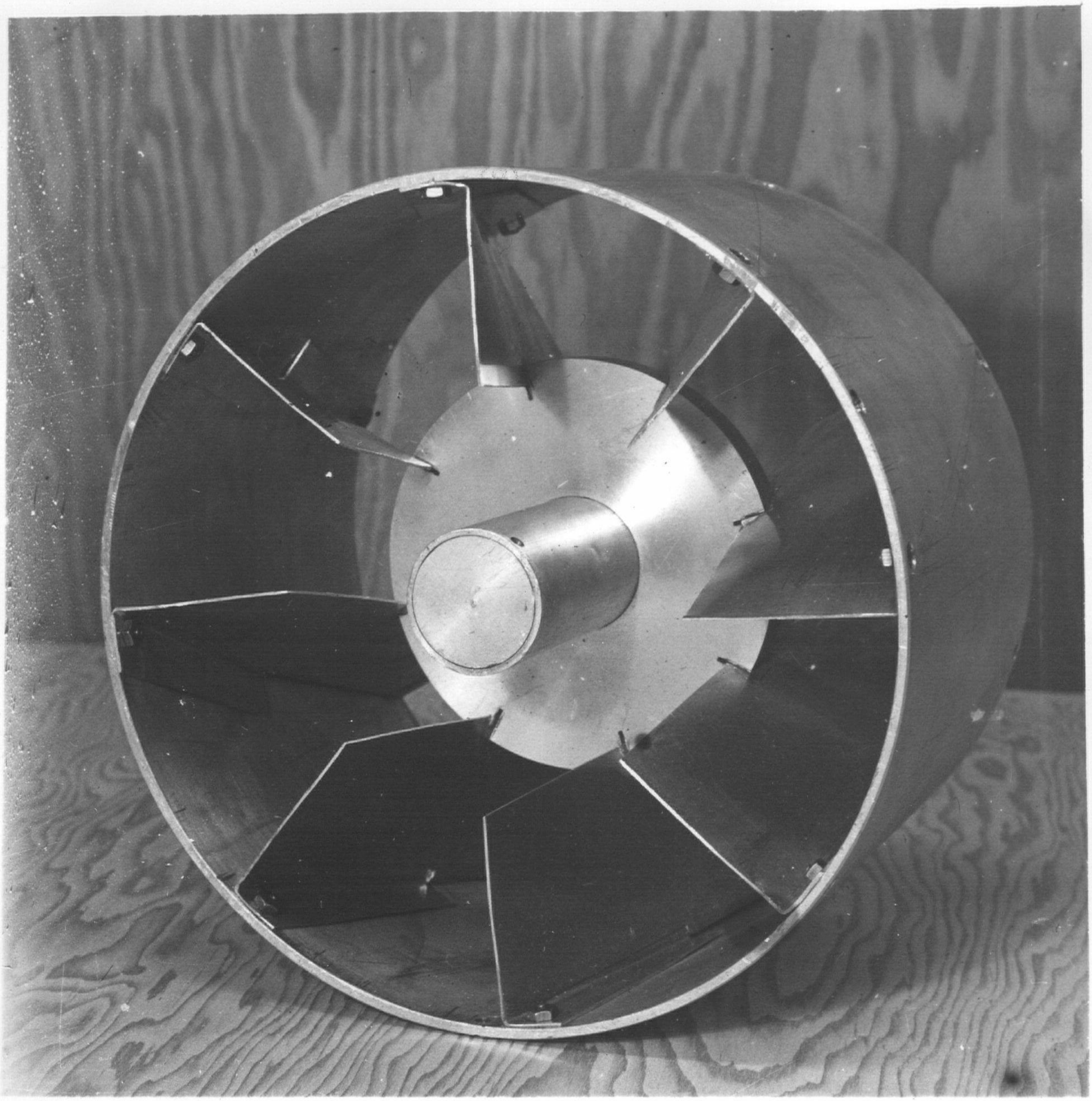


Figure 2 - Complete Assembly

magnetic coil wound around its centre section. A system of baffles defines the trajectories of the particles from the source. These particles are bent through a spiral path to focus at the window of a bell-type Geiger counter. The centre baffle, which is shown in fig. 3, is designed to stop either positive or negative beta particles from passing through the spectrometer, depending on the direction of the current which is passed through the focussing coils. Deutsch et al[14] have shown that the pitch is almost constant for trajectories having different radii. In the course of the present research this baffle has proven to be most efficient in the elimination of the electrons of the opposite sign. Daykin[12], however, reports a 25% loss in the counting rate of the desired sign of electrons with the spiral baffle, probably due to too large a pitch.

The magnet coil is made up in four co-axial layers which may be used individually or in series. It is easily shown that the sign of the gradient of the field in the radial direction is opposite to that required for the best momentum discrimination. This effect can be minimized by using only the outermost layer of the coil, which of course requires much heavier currents. Therefore a compromise must be made between the consideration of focussing and the convenience of covering an ample range of momenta. In this work only the two outermost sections were utilized.



Spiral Baffle

Fig.3

Current Regulator

Only those particles, travelling in the correct direction, with momenta such that they will be focussed at the counter window, will satisfy the focussing conditions determined by the strength of the magnetic field of the focussing magnet. Since there is no ferro-magnetic material in or near the spectrometer the strength of the field will be directly proportional to the current through a standard manganin resistance of approximately .08 ohms in series with the coil. The voltage drop across this resistance is compared to the voltage set on a Rubicon Potentiometer and the unbalanced voltage used to drive the current stabilizer described by Lindenfeld, Mathews, Ozeroff and Daykin[14].

Geiger Counter

The thin window Geiger Counter shown in fig. 4 was designed in this laboratory to eliminate as much as possible the use of wax seals. The only wax used is the very thin layer which seals the mica window between the brass flanges. The copper anode is ¾" in diameter. The .005" tungsten anode wire is hard soldered to an advance wire which in turn is soft soldered to the top end of the Kovar seal through which it projects and which in turn is soldered to the top of the metal outer case of the counter. A short section of Nonex glass tube is fastened to the glass sleeve of the Kovar seal which is then soldered upside down onto the outer case of the counter. This assembly

Figure 4

GEIGER COUNTER

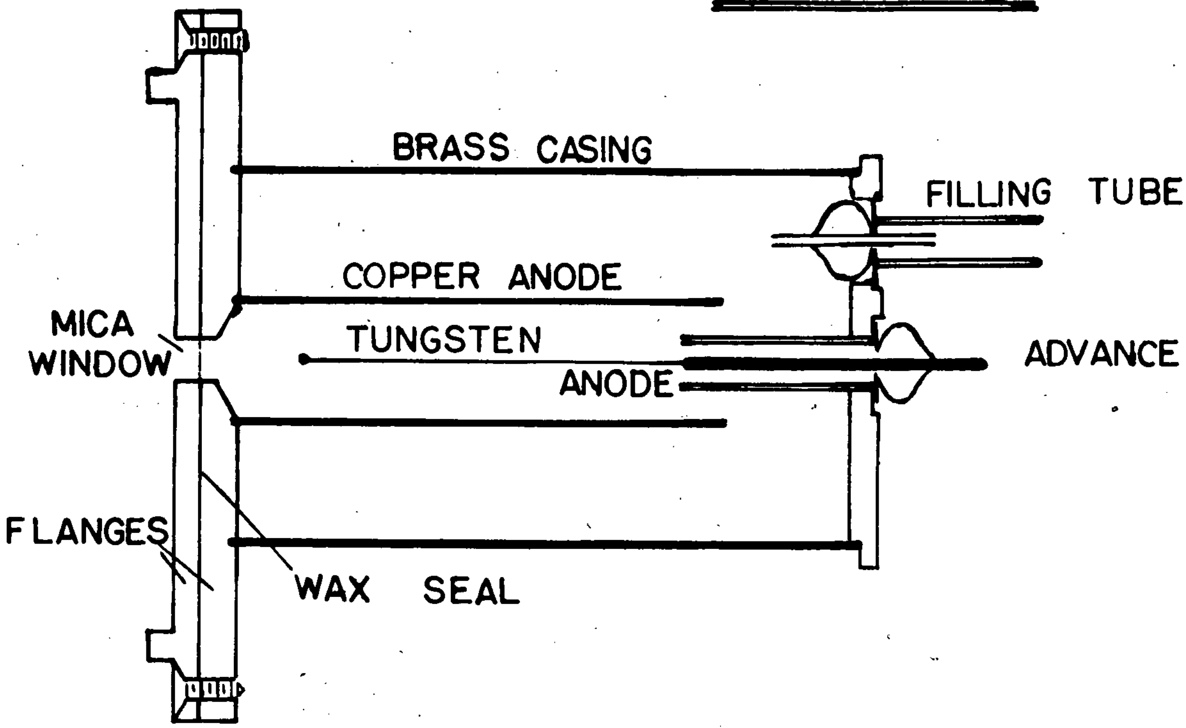
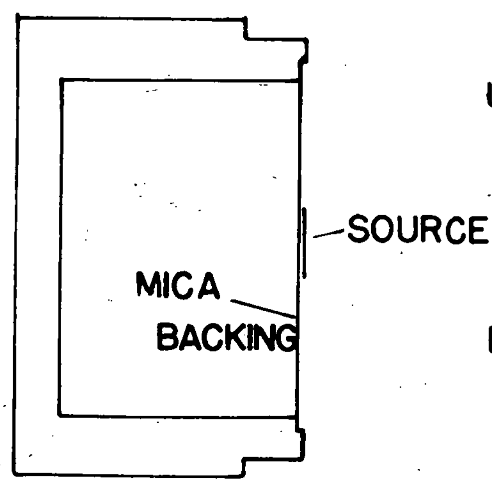
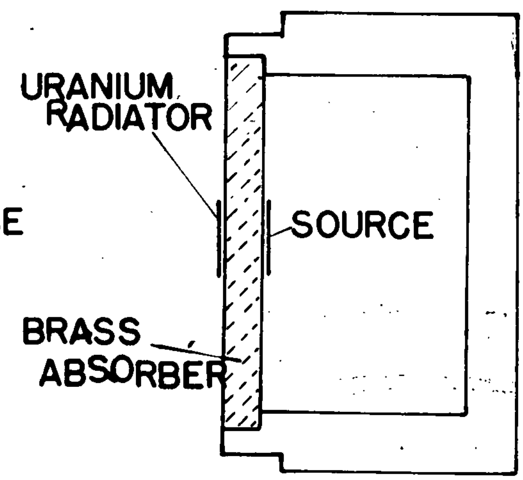


Figure 5(a)



FOR ELECTRONS

Figure 5(b)



FOR GAMMAS

is used to fill the counter and the glass tube is then sealed off, thus eliminating the use of a stopcock and the possible leakage thereof. The 2.8 mg/cm^2 mica window is sealed to the base of the counter with Plicene wax which has been dissolved in boiling turpentine and painted onto the brass flanges. The counter was filled with 1.5 cm. of alcohol and 8.5 cm. of argon.

Amplifier

The arrangement of the laboratory required the use of a ten foot cable to carry the counter pulses to the amplifier. To avoid the loading of the counter by the cable, a cathode follower is used to feed the pulses through the cable into the amplifier. A matching resistance of 100 ohms is used at the output end of the cable. Amplifier is a two-stage grounded grid triode type preceded by a cathode follower. The pulse is sufficiently amplified by the first stage to saturate the second stage and provide 60 volt pulses of equal amplitude for the scalar. This amplitude of pulse allows a scalar discrimination bias of 15 volts which is quite sufficient to eliminate most of the counts due to stray pickup, while at the same time keeping the counting rate completely independent of discriminator bias fluctuations. The plateau obtained with this circuit and the counter described above has been satisfactory and has remained stable over the whole period during which this research has been carried out.

Compensating Coils

The horizontal component of the earth's magnetic field is compensated for by a pair of Helmholtz coils wound on a frame about the spectrometer table. The current is regulated against line voltage variations by the use of two ballast tubes in series with the 10 ohm coils. The excess of the normal 1.7 amps above the required .94 amps is shunted through a rheostat. This regulation is sufficient to care for normal hour to hour line voltage fluctuation.

Source Arrangement

The 1 millicurie Zn^{65} source was produced by slow neutron irradiation in the Chalk River pile of a sample of pure Zn^{64} in the form of a thin square foil, 25 mg/cm^2. This form of a source was most adaptable for the various types of investigation which were required in this research. For counting positrons and negatrons the source was fastened to a 2 mg/cm^2 mica backing as illustrated in fig. 5a. For counting the photo-electrons ejected from a uranium radiator, the source was fastened to one side of a 1/16" thick brass plate with the uranium radiator of 90 mg/cm^2 on the other side. The thickness of the brass absorber was calculated from the Feather formula to be sufficiently thick to stop the most energetic beta particles which were observed in the negatron spectrum. In order to obtain the Compton background an identical brass absorber was instituted without the uranium radiator. This arragement is shown in fig. 5b. Care was taken to ensure that the position of the source for beta counting was identical to the position of the uranium radiator in order to provide a cross check for the calculations of energies.

Calibration of the Instrument

This instrument was calibrated on the basis of the .607 mev gamma line of radium. This energy was obtained by Ozeroff[3] on the basis of the well known F line of thorium B as measured in a similar instrument. The potentiometer reading corresponds then to the energy of gamma line minus the binding energy of the correct level of the radiator, since the photo-electric effect is used. In the above cases the K shell of lead with a binding energy of 87.5 kev is appropriate. The potentiometer setting can then be translated directly into $H\rho$ values.

Statistical Accuracy

The statistical accuracy of all points on the spectra was better than 2%, while those points in the regions from which important data might be expected, had a statistical accuracy approaching 1%. This entailed a minimum of 20 minutes counting per point in the first case and as much as 60 minutes in the latter.

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RESULTS

Negatron Spectrum

The negatron spectrum is shown in the graph in fig. 6. A Fermi plot of this spectrum was prepared and no β^- distribution could be recognized, indicating the continuum was due largley to Compton recoil electrons. In other words any β^- emission must be of so low an activity as to be lost in the Compton distribution which is produced by gamma-rays in the Zn source. A very pronounced spectral line is in evidence which can be identified as an internal conversion line of Cu^{65}. With the binding energy for Cu as calculated from the data in the Handbook of Physics and Chemistry at .088 mev, this leads to a gamma-ray energy of 1.13 mev $\pm$ .005.

Positron Spectrum

The positron spectrum is shown in fig. 7 and the Fermi plot of this spectrum is shown in fig. 8. The extrapolated end point is fitted by the method of least squares, using the 11 points indicated by the arrows in fig. 8. The results indicate an end point energy of .320 $\pm$ .003 mev.

Gamma-Ray Spectrum

The gamma-ray spectrum shown in fig. 9 displays the high intensity photo-electric peak from the K shell of uranium, as well as the less pronounced L shell peak. A rather weak peak at .3 V. corresponding to a gamma-ray energy of .513   .003 mev is identified as annihilation radiation. Using the value .114 mev for the binding energy of the K shell and .020 mev for the L shell, the gamma-ray energy is in both cases 1.12   .005 mev.

A close examination of the high energy end of the Compton distribution in fig. 9 shows a spectral configuration which may be due to a low intensity gamma-ray. Using a re-arranged version of the well-known Compton scattering formula, we can determine the gamma-ray energy responsible for the maximum recoil electron. This may be expressed as:

$$E_\gamma = \frac{E_m \pm \sqrt{E_m^2 + 2E_m mc^2}}{2}$$

Where E_γ = energy of the gamma-ray

E_m = maximum energy of the Compton recoil electron in the forward direction (which in this case is 1.14 mev).

This leads to the result that:

$$E_\gamma = 1.4 \pm .1 \text{ mev.}$$

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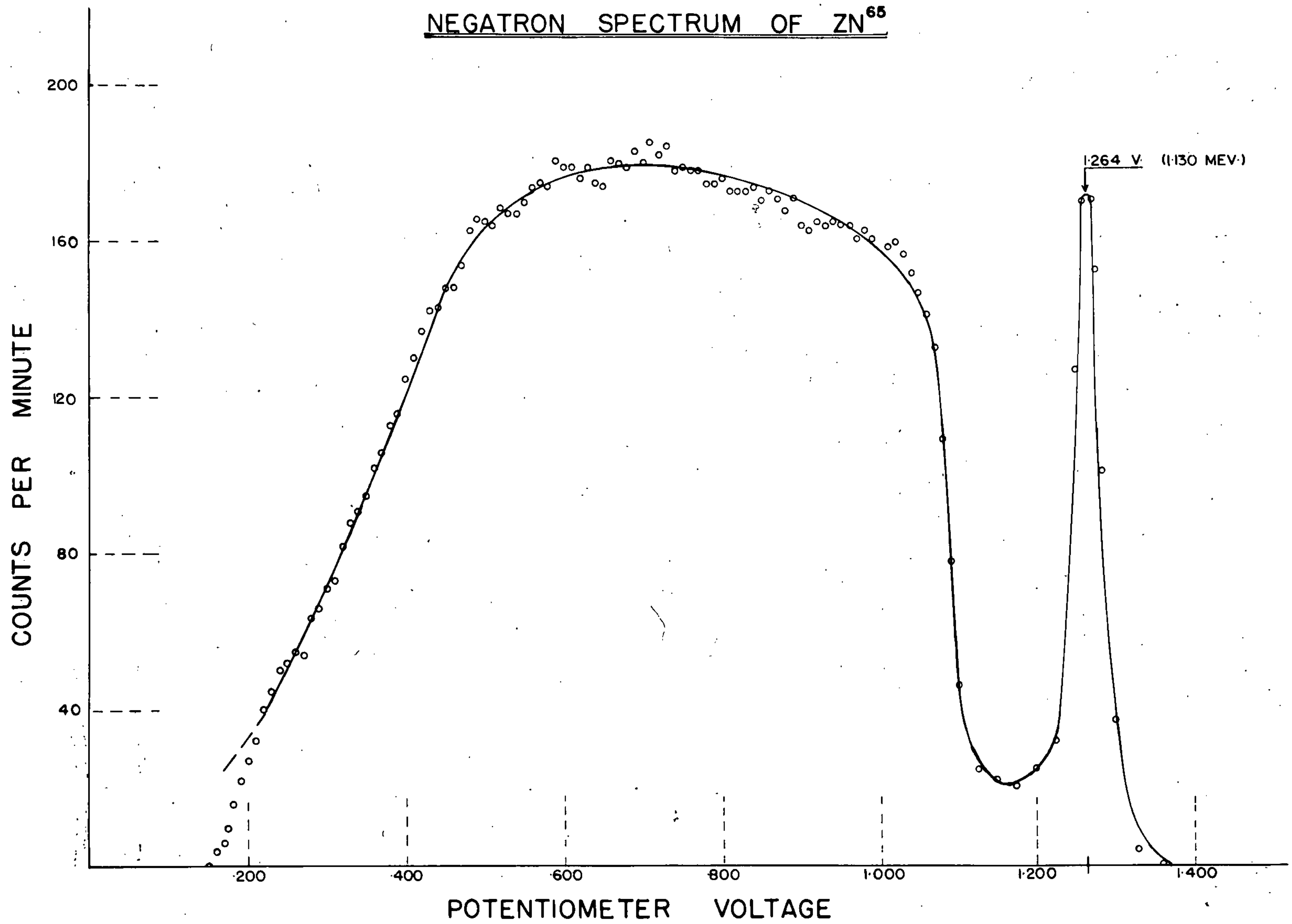

NEGATRON SPECTRUM OF ZN65
COUNTS PER MINUTE
200
160
120
80
40
·200
·400
·600
·800
1·000
1·200
1·400
1·264 V (1·130 MEV·)
POTENTIOMETER VOLTAGE

Figure 6

Figure 7

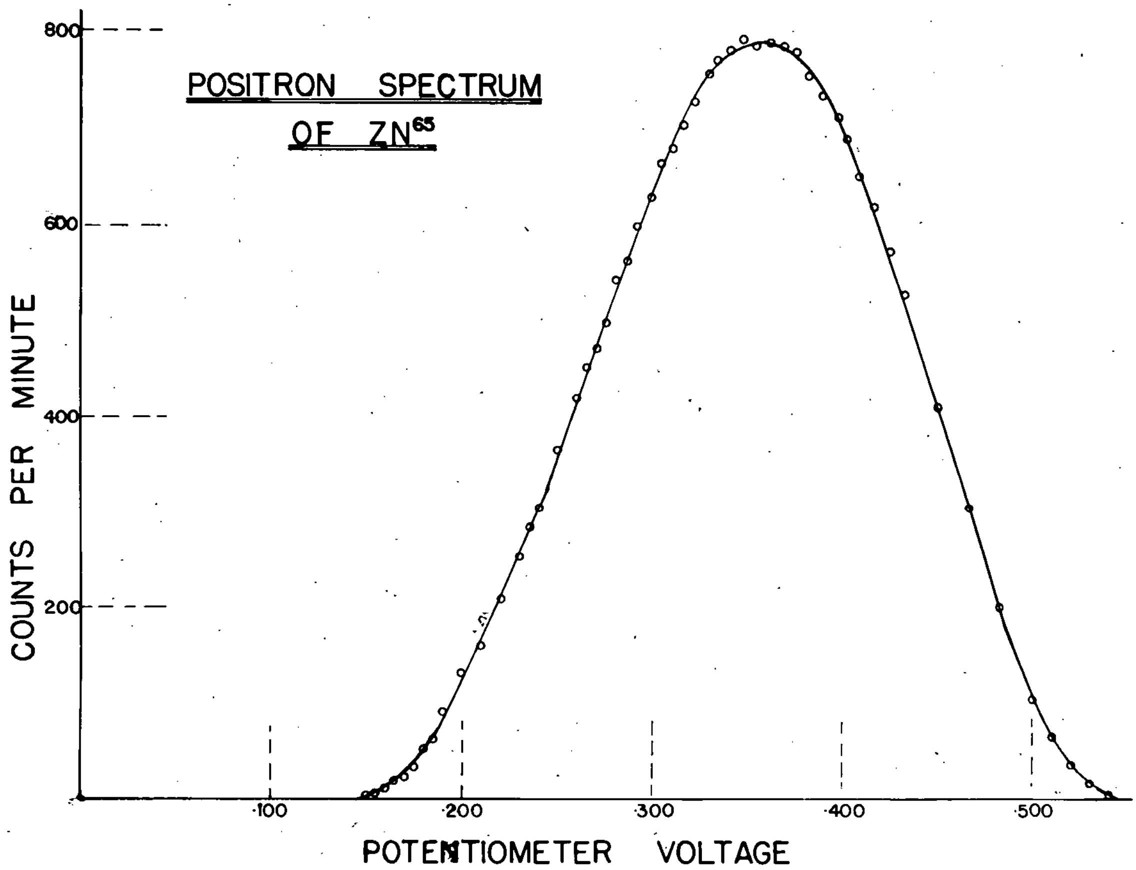
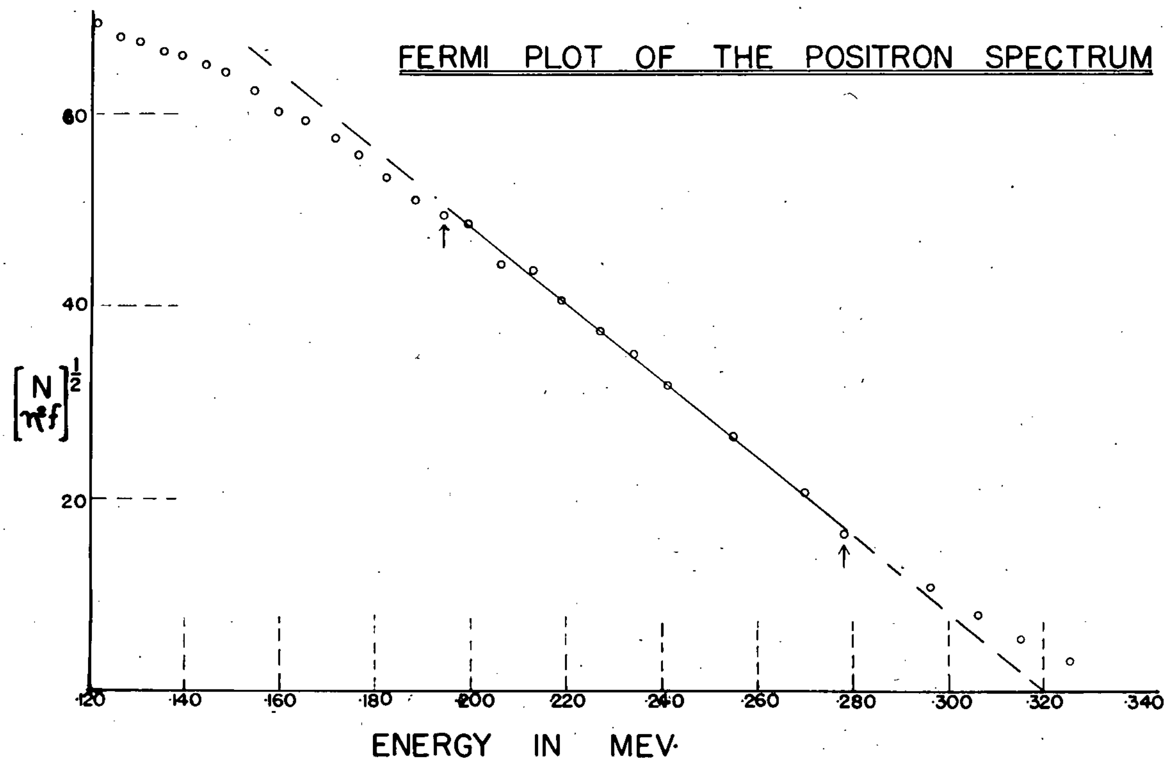


Figure 8



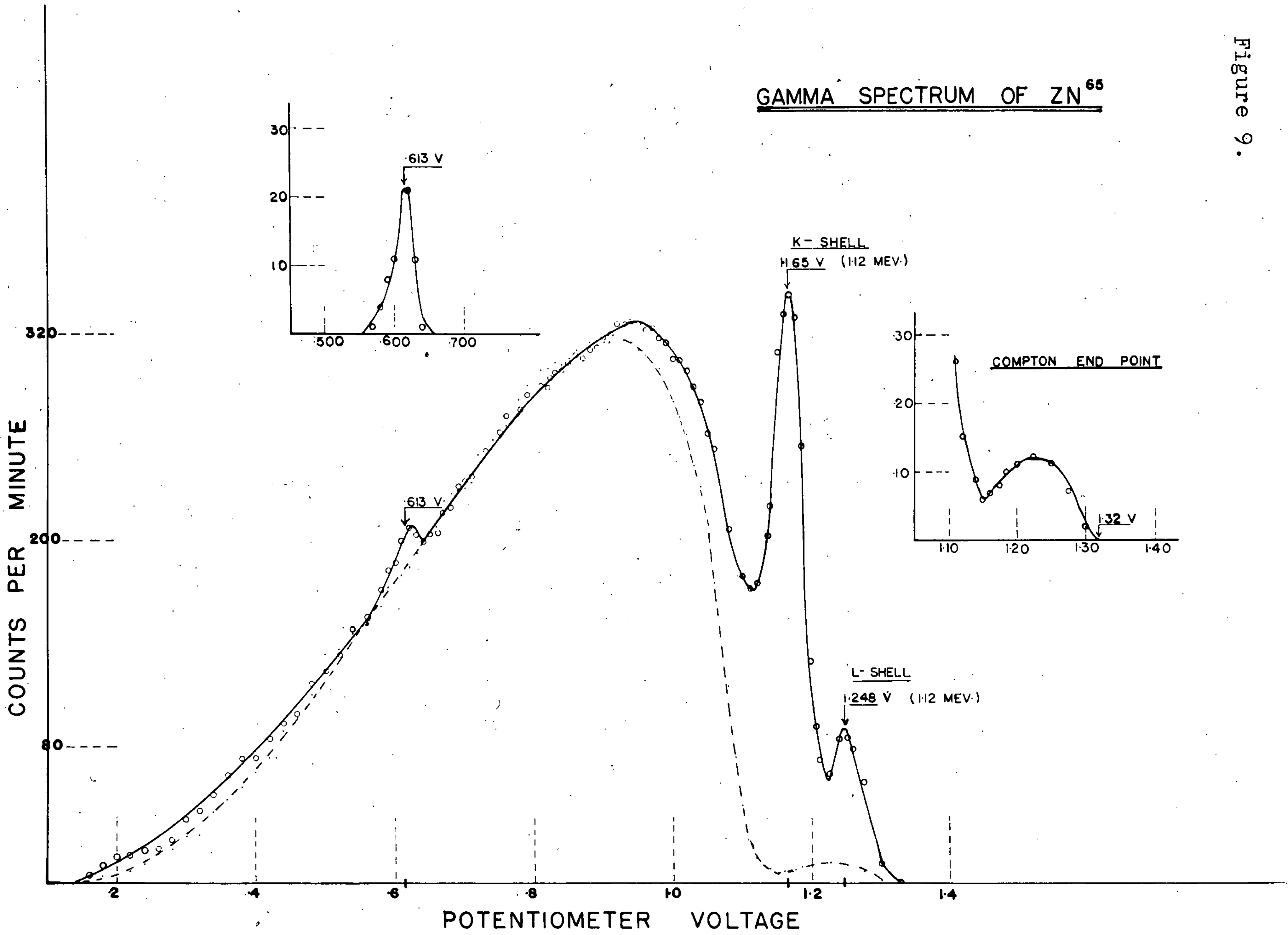

GAMMA SPECTRUM OF ZN 65
COUNTS PER MINUTE
POTENTIOMETER VOLTAGE
320
200
80
·2
·4
·6
·8
1·0
1·2
1·4
·613 V
K- SHELL
1·165 V (1·12 MEV·)
L- SHELL
1·248 V (1·12 MEV·)
30
20
10
500
600
700
·613 V
COMPTON END POINT
30
20
10
1·10
1·20
1·30
1·40
1·32 V

Figure 9.

CONCLUSIONS

The results obtained in this research agree in their main features with those of the most recent investigations. The rather high intensity internal conversion electrons found, confirm in part the assumptions of Delasso et al[4] regarding the presence of negatrons.

The positron end point agrees with the results of W. C. Peacock[11] and is 2% lower than that of P.N. Daykin[13].

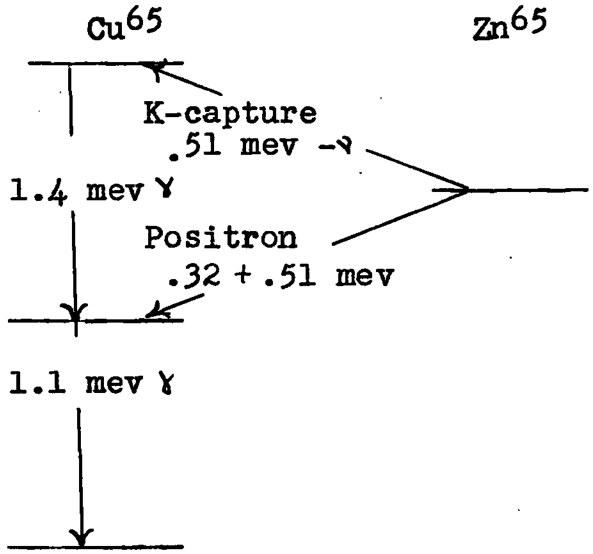
The gamma-ray energies .513 ± .002 mev and 1.12 ± .005 agree well with those of Jensen, Laslett and Pratt[12] but are slightly lower than the results of Deutch, Elliott and Roberts [9]. However the gamma energy as measured from the internal conversion line 1.13 ± .005 agrees closer with the result of the latter investigators.

The findings of Sagane et al[7] with respect to the positron end points seem most unlikely, in view of the results of this investigation, while the three gamma-ray energies reported by Watase et al[8] in the ratio 1:1:1 are even more improbable, since the energies 1.0, .65, and .45 mev are well within the possibility of detection in the intensities claimed, with our instrument.

The gamma-ray energy of 1.4 ± .1 mev first reported here must be considered with caution in view of the low activity source available for the measurement of this reaction.

This gamma line is inherently weaker than the 1.1 mev line if the hypothesis which is put forward below has any significance. The confirmation of the 1.4 mev line must await either a beta ray spectrometer investigation with a stronger source, or perhaps better, an investigation using a pair spectrometer with the source in a strong flux of neutrons.

A decay scheme based on these results can be tentatively advanced:



Before this scheme can be accepted with less than the utmost caution, further research must be undertaken. The ratio of gamma to positron emission must be re-examined. It should be noted that the arrangement of the source militates against counting the annihilation radiation, also the presence of strong internal conversion must affect the ratio previously accepted. Not only X-gamma and positron-gamma but also gamma-gamma coincidences must be measured, before a comprehensive analysis of the decay scheme of Zn^{65} can be verified.

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BIBLIOGRAPHY

1. J. J. Livingood
Phys. Rev., 50, 425, 1936

2. C. Perrier, M. Santangelo, E. Segre
Phys. Rev., 53, 104, 1938

3. S. W. Barnes, G. Valley
Phys. Rev., 53, 946, 1938

4. L. A. Delsasso, L. N. Ridenour, R. Sherr, M. G. White
Phys. Rev., 55, 113, 1939

5. J. J. Livingood, G. T. Seaborg
Phys. Rev., 55, 457, 1938

6. L. W. Alvarez
Phys. Rev. 54, 486, 1938

7. R. Sagane, S. Kojima, G. Miyamoto
Proc. Phys. Math. Soc. Japan, 21, 728, 1939

8. Y. Watase, J. Itoh, E. Takeda
Proc. Phys. Math. Soc. Japan, 22, 90, 1940

9. M. Deutsch, A. Roberts, L. G. Elliott
Phys. Rev., 61, 389, 1942

10. W. M. Good and W. C. Peacock
Phys. Rev., 69, 680, 1946

11. W. C. Peacock
Plutonium Project Report, Mon. N-432, 56, 1942.
(prob. restricted circulation)

12. E. N. Jensen, L. J. Laslett, W. W. Pratt
Phys. Rev., 75, 529, 1949

13. P. N. Daykin
M. A. Thesis, University of British Columbia

P. Lindenfeld, M. A. Thesis,
University of British Columbia

M. J. Ozeroff,
M. A. Thesis, University of British Columbia

14. M. Deutsch, L. G. Elliott, R. D. Evans,
R. S. I., 15, 178, 1944.

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