contradiction may seem more easily digestible, it meets with difficulty in accounting for the experimental results of Cocconi,[7] Janossy, and Broadbent,[8] and Salvini and Tagliaferri,[9] who found that the number of penetrating particles in extensive air showers, recorded under absorbers of different atomic number, was independent of Z. As has been pointed out by Ferretti,[14] this would imply a cross section for meson production proportional to Z^2.

[14] B. Ferretti, Nuovo Cimento **3**, 301 (1946).

The authors wish to thank Professor H. A. Bethe and especially Dr. G. Cocconi for helpful discussions of the problems associated with air showers. They are grateful to Professors B. E. Cohn and M. Iona of Denver University for assistance in the arrangements for performing the experiment, and to the cosmic-ray group of M.I.T. for the supply of electrical power on Mt. Evans.

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The Beta- and Gamma-Spectra of Gallium Irradiated by Slow Neutrons*

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The beta- and gamma-ray spectra of gallium irradiated with slow neutrons have been investigated with a thin-magnetic-lens spectrometer. Probable beta-ray end points for Ga^{72} at 3.15 Mev (9.5 percent), 2.52 Mev (8 percent), 1.48 Mev (10.5 percent), 0.955 Mev (32 percent), and 0.64 Mev (40 percent) were found. A conversion line occurring in about 0.5 percent of the disintegrations was observed at 0.68 Mev. Gamma-rays of 2.51 Mev (26.5 percent), 2.21 Mev (33 percent), 1.87 Mev (7.8 percent), 1.59 Mev (4.5 percent), 1.05 Mev (4.5 percent), 0.84 Mev (100 percent), and 0.63 Mev (24 percent) were also found for Ga^{72}. A nearly complete decay scheme for Ga^{72} is suggested.

The beta-ray spectrum of Ga^{70} (20.5 min.) has also been observed with the spectrometer. The Kurie plot is linear from the end point of 1.65 Mev to 0.4 Mev. No evidence of conversion lines in this energy interval was found.

I. INTRODUCTION, Ga^{72}

IN 1935 Amaldi *et al.*[1] reported a 23-hour strong gamma-ray activity in gallium irradiated with a slow neutrons. Chemical identification, assignment of the activity to Ga^{72}, and accurate measurement of the half-life (14.1 hr) were accomplished by Sagane[2] who observed hard beta-radiation as well as the hard gamma-radiation. This isotope has also been produced by Ga(d,p),[3] Ge(n,p),[4] Ge(d,α)[4] and by decay of the uranium fission product Zn^{72}.[5]

The maximum end point of the beta-ray spectrum was first reported to be 1.71 Mev by Sagane *et al.*[6] using a cloud chamber. Livingood and Seaborg,[7] using absorption methods, later reported an end point at 2.6 Mev. Siegel and Glendenin,[5] using absorption in Al, reported two groups of beta-rays with end points of 3.1 Mev (35 percent) and 0.8 Mev (65 percent) while Mitchell *et al.*[8] by the same method found 2.3 Mev and 0.77 Mev. In a preliminary report[9] on the present work in which a lens spectrometer was used, the author reported five apparent end points, 3.15 Mev (9.5 percent), 2.52 Mev (8 percent), 1.48 Mev (10.5 percent), 0.95 Mev

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[1] E. Amaldi, O. Agostino, E. Fermi, B. Pontecorvo, F. Rasetti, and E. Segrè, Proc. Royal Soc. **A149**, 522 (1935).

[2] R. Sagane, Phys. Rev. **53**, 212 (1938); **55**, 31 (1939).

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[4] R. Sagane, G. Miyamoto, and M. Ikawa, Phys. Rev. **59**, 904 (1941).

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[6] R. Sagane, R. S. Kojima, and G. Miyamoto, Proc. Phys. Math. Soc. Japan **21**, 728 (1939).

[7] J. J. Livingood and G. T. Seaborg, Rev. Mod. Phys. **12**, 30 (1940).

[8] A. C. G. Mitchell, E. T. Jurney, and M. Ramsey, Phys. Rev. **71**, 324 (1947).

[9] S. K. Haynes, Report MonP-368, Clinton Laboratories, Sept. 1, 1947; also Phys. Rev. **73**, 187 (1948).

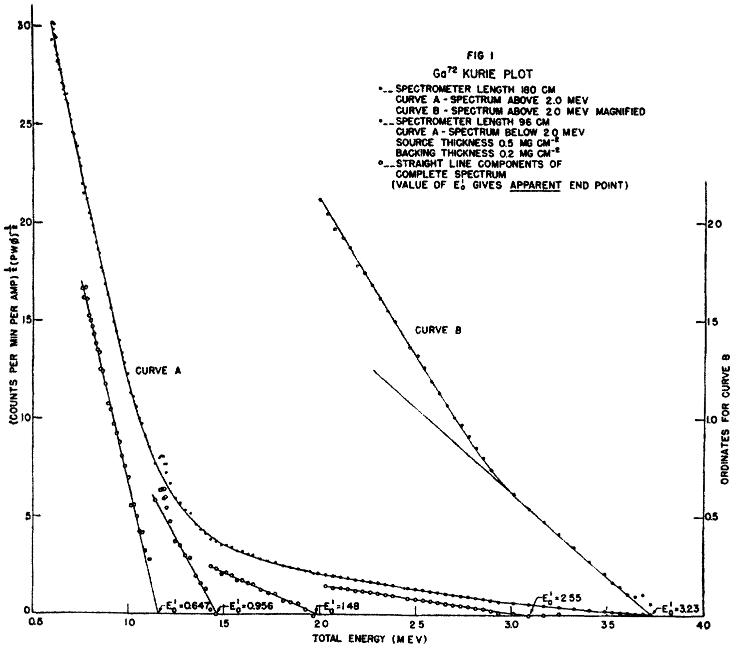

FIG. 1. Kurie Plot of the beta-radiation from Ga^{72} showing the resolution into five straight line components. The reality of the components cannot be judged from this curve alone. The energies of the upper two end points have not been corrected for resolving power.

(32 percent), and 0.64 Mev (40 percent), of which certainly all but perhaps the one at 1.48 Mev represented real end points. More recently, Mitchell *et al.*[10] have reported three end points at 3.09 Mev, 2.2 Mev, and 0.79 Mev.

Mandeville[11] first measured the gamma-rays using Compton recoils in a spectrometer. He found two of equal intensity at 1.17 Mev and 2.65 Mev. Miller and Curtiss[12] using photo-electrons in a lens spectrometer reported gamma-rays of 0.64 Mev, 0.84 Mev, and 2.25 Mev, with intensity ratios of roughly 1 to 6 to 6. Coincidence absorption measurements by Mitchell *et al.*[8] gave 2.4 Mev and 0.82 Mev for the gamma-rays. The same method used by Mandeville and Scherb[13] gave 2.29 Mev. Wattenberg[14] studying photoneutrons reported an energy of 2.50 Mev and at least one other line above the photo-neutron threshold for Be. In the preliminary reports[9] of this work using a lens spectrometer lines were reported at 2.51 Mev (26 percent), 2.21 Mev (31.5 percent), 1.87 Mev (7.5 percent), 1.05 Mev (4.5 percent), 0.84 Mev (100 percent), 0.63 Mev (18.5 percent) and possibly one at 1.60 Mev (4.5 percent). Mitchell *et al.*,[10] also using a lens spectrometer, have reported gamma-rays at 0.64 Mev, 0.71 Mev, 0.84 Mev, 2.15 Mev and one of higher energy. Deutsch and Siegbahn[15] first observed a conversion line at 0.72 Mev. This was later reported by the author[9] as 0.68 Mev, and by Mitchell *et al.*[10] to be 0.71 Mev. Bowe, Goldhaber *et al.*[16] have found the half-life of this conversion line to be 0.5×10^{-6} sec. and believe it to arise from a $0\rightarrow0$ transition with no parity change and, therefore, to be 100 percent converted. If this interpretation of the conversion line is correct, the 0.71 Mev gamma-ray reported by Mitchell *et al.*,[10] if real, cannot be associated with the same transition as the conversion line.

Beta-gamma-coincidences as a function of beta-ray absorption[8, 13] not only substantiate the complexity of the beta-ray spectrum but also indicate that very few if any of the beta-transitions go to the ground state of Ge^{72}. The latter conclusion is also supported by the figure of 2.6 Mev of gamma-ray energy per beta-particle given by Barker.[17]

[10] A. C. G. Mitchell, B. D. Kern and D. J. Zaffarano, Phys. Rev. **73**, 1220A (1948). *Note added in proof*: See Phys. Rev. **73**, 1431 (1948) for a fuller report of this work.
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[12] L. C. Miller and L. F. Curtiss, CP-3102, June 1945, and Phys. Rev. **70**, 983 (1946).
[13] C. E. Mandeville and M. Scherb, Phys. Rev. **72**, 520 (1947).
[14] A. Wattenberg, Phys. Rev. **71**, 497 (1947).
[15] M. Deutsch and K. Siegbahn, Private communication quoted in reference 15.
[16] J. C. Bowe, M. Goldhaber, R. D. Hill, W. E. Meyerhof, and O. Sala, Phys. Rev. **73**, 1219 (1948).
[17] E. C. Barker, Phys. Rev. **72**, 167 (1947).

This paper will present the experimental evidence both for the previously published conclusions[9] and for some new results which make it possible to suggest an almost complete decay scheme for Ga^{72}.

II. BETA-RAY SPECTRUM OF Ga^{72}

The beta-ray spectrum of Ga^{72} was run four times on a thin lens spectrometer under experimental conditions which differed as to source thickness, baffle system, and spectrometer length (distance from source to counter).

Two sources were used. Source *A* consisted of 1 mg/cm² gallium evaporated[18] onto 1 mil polystyrene ($\sim$3 mg/cm²). The layer of gallium was 9 mm in diameter and the polystyrene film 12 mm in diameter. After 16 hours irradiation in the Clinton pile, this source was cemented onto a thin walled lucite cylinder 12 mm in diameter and about 5 cm long which was mounted in the source holder of the spectrometer. Source *B* had the same diameter as source *A* and was prepared and irradiated in the same way. After removal from the pile the source was placed upside down on a 0.2 mg/cm² Formvar film 1 inch in diameter. The polystyrene and more than $\frac{2}{3}$ of its almost negligible activity were then dissolved off, leaving 0.5 mg/cm² of gallium on the Formvar film. In every case the 20 minute activity of Ga^{70} was allowed to decay completely before the Ga^{72} measurements were started.

Three baffle systems were used. Baffle system *A* was essentially that of Deutsch *et al.*[19] Baffle system *B* consisted of about 10 aluminum baffles with edges bevelled to present a minimum scattering surface to the beam. Notches which act as electron catchers were also machined in the surface of the central lead absorber. Baffle system *C* was similar to system *B* but arranged for a spectrometer length of 180 cm.

The 180 cm length was used to investigate the high energy end of the spectrum since the upper energy limit of the spectrometer with a length of 100 cm was 2.6 Mev. In all runs at 100 cm the inner and outer radii of the annular aperture were 6.6 cm and 7.6 cm respectively. With a 9 mm diameter source the resolving power was about 3.5 percent. In the run at 180 cm the radii of the aperture were 2.6 cm and 7.6 cm while the resolving power was about 10 percent. The counter window had a thickness of about 2.5 mg/cm² in all cases. Calibration of the spectrometer was made with annihilation radiation from Cu^{64} using photoelectrons from a gold radiator. The radiator was approximately 0.8 mg/cm² thick and of the same diameter as the gallium beta-ray sources. The spectrometer constant was also calculated from the coil constants and the calculated and measured values agreed to within less than one percent.

Figure 1 shows a Kurie plot of the complete beta-ray spectrum. The high energy portion was run with source *A* and spectrometer length of 180 cm while the low energy portion was run with source *B* and baffle-system *B*. In the course of the four runs (the other two were source *A*,

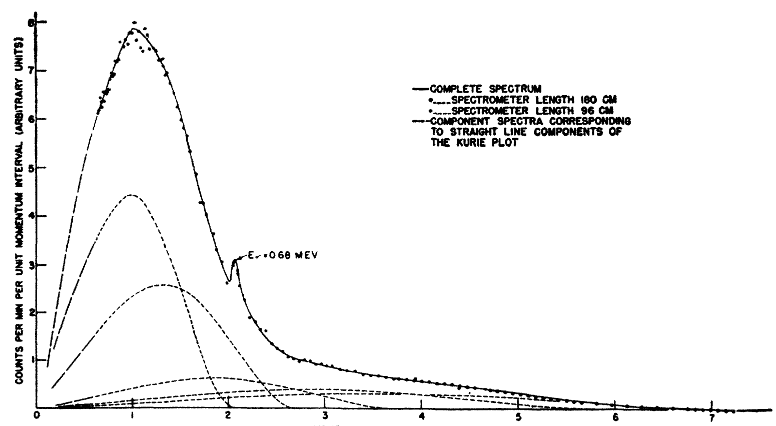

FIG. 2. Normal beta-ray spectrum of Ga^{72} showing the possible component spectra and the conversion line at 0.68 Mev.

[18] S. K. Haynes, Phys. Rev. **71**, 832 (1947).
[19] M. Deutsch, L. G. Elliott, and R. D. Evans, Rev. Sci. Inst. **15**, 179 (1944).

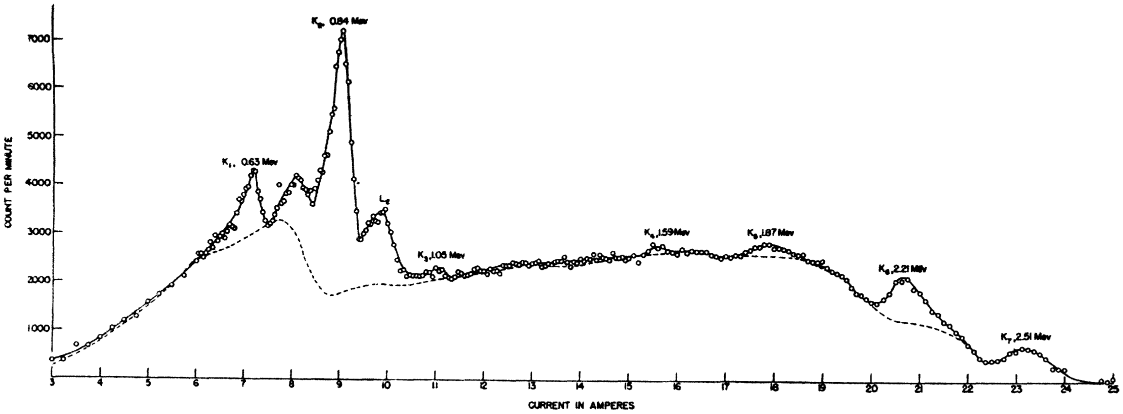

FIG. 3. Photoelectron plus Compton electron spectrum of Ga^{72} using a uranium radiator of thickness 74.9 mg/cm². Broken line shows the estimated background from the copper capsule.

Baffle-system A and source A, Baffle-system B) it was shown that the shape of this spectrum above 0.2 Mev is: (1) independent of change in source thickness, (2) independent of a change of baffle-system, and (3) has a half life of 14.1 ± 0.5 hours at all points. In the first run the spectrum was observed five times over an interval of more than 30 hours. Spectroscopic analysis of the sources, observation (3), the known half lives, activation cross sections, and end points of possible impurities show that impurities cannot contribute appreciably to the spectrum. The spectrum shown in Fig. 1, above 0.2 Mev, is, therefore, characteristic of Ga^{72} and, except for finite resolving power, is independent of instrumental effects.

The curve obviously represents a complex beta-ray spectrum. Since the half life and energies of Ga^{72} are not in the allowed range, each of the component spectra has an unknown shape which renders difficult, if not impossible, the separation of the complete spectrum into its component parts. It is instructive, however, to see how many end points can be obtained on the assumption that each component beta-particle group has a straight Kurie plot. By the usual method of extraction the five end points shown in Fig. 1 are obtained.

The two upper energies given in the figure are too high because of the poor resolving power of the spectrometer when the 180 cm length and full aperture were used and because of the short energy interval (less than 20 percent of the full energy) available for drawing the straight Kurie line. The upper energy was corrected by assuming a Gaussian resolving function with a 10 percent half-width and applying it to a linear Kurie plot. The best straight line was drawn through the upper 20 percent of the resulting curve. The difference between the resulting end point and the original assumed end point gives the correction to be subtracted which in this case was 0.08 Mev. The corrected Kurie line was then used in a redetermination of the second highest end point. The corrected value of the latter was 2.52 Mev as against the initial value of 2.55 Mev. The corrected energies for the two upper end points and the *average* of four runs for the three lower end points are as follows: 3.15 Mev (9.5 percent), 2.52 Mev (8 percent), 1.48 Mev (10.5 percent), 0.955 Mev (32 percent), and 0.64 Mev (40 percent). These intensities are based on the assumption of a straight line Kurie plot and may, therefore, be subject to correction; in fact, the decision as to the existence of all these end points must depend on the gamma-ray spectrum and on coincidence measurements, if such are feasible.

Figure 2 shows the plot of counts per unit momentum interval against momentum in mc units. The conversion line which appears at 0.68 Mev in Fig. 1 can be shown from Fig. 2 to occur in approximately 0.5 percent of the disintegrations. Each of the five straight line components of the Kurie plot is shown by a broken line in Fig. 2.

III. GAMMA-RAY ENERGIES OF Ga^{72}

The gamma-ray source of Ga^{72} consisted of a cylinder of metallic gallium 0.140-inch in diameter and 0.070-inch in length. The temperature of this cylinder was kept below its melting point of 30°C during all manipulations. After irradiation in the pile to a source strength of 10 to 20 millicuries the solid metallic gallium was transferred to a cylindrical copper capsule with side wall thickness of 0.025-inch and an end wall thickness of 0.060-inch. These thicknesses were the smallest which were sufficient to stop all beta-rays which could enter the spectrometer and hence gave a minimum background of Compton electrons. Complete runs were made with the gallium filled capsule alone and also with a uranium radiator of the same diameter as the capsule (0.190-inch) and 74.9 mg/cm² thick. Partial runs were made with uranium radiators[20] 12.8 mg/cm², 21.9 mg/cm², and 42.2 mg/cm² thick. Calibration runs on annihilation radiation from Cu^{64} were made with uranium radiators of 12.8 mg/cm², 21.9 mg/cm², 74.9 mg/cm² and with a gold radiator of 0.8 mg/cm². One run was made on Na^{24} with a uranium radiator of 74.9 mg/cm² in order better to understand the shape of the photoelectron lines and of the Compton distributions from two widely separated gamma-rays of equal intensity. Observations of this type on other elements were prevented by lack of time.

In Fig. 3 the Compton plus photoelectron counting rate using a 74.9 mg/cm² uranium radiator is plotted against lens current which is proportional to electron momentum. Points were taken at currents separated by about 0.5 percent and about 10^4 counts were taken per point except between 18.5 and 14.5 amp. Each of the points between 18.5 and 16.5 amperes represents the average of six runs or a total of about 6×10^4 counts per point. Two additional runs were made from 16.5 to 14.5 amperes (not included in Fig. 3) as well as one extra run on the Compton distribution in order to decide whether or not a line existed at 1.59 Mev. Figure 4 shows the photoelectron spectrum alone (including all the data between 16.5 and 14.5 amp) obtained by subtracting the Compton distribution. This subtraction is not as straightforward as it might appear, for a uranium radiator of thickness 74.9 mg/cm² scatters the Compton electrons coming from the copper in such a manner as to reduce

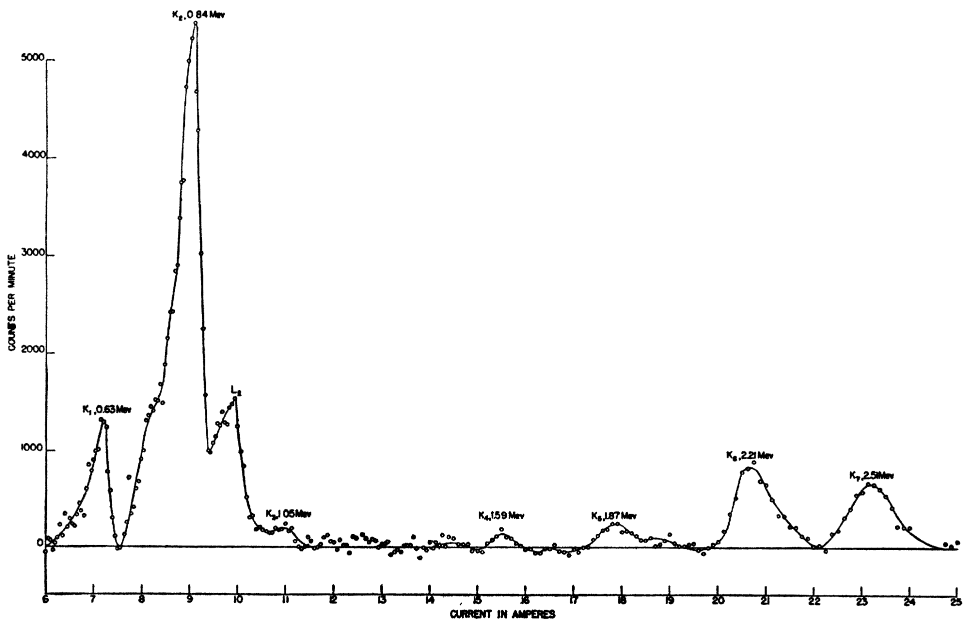

FIG. 4. Photoelectron spectrum of Ga^{72} from a uranium radiator of thickness 74.9 mg/cm².

[20] The author wishes to express his indebtedness to Dr. L. F. Curtiss of the Bureau of Standards for the uranium foil from which these radiators were made.

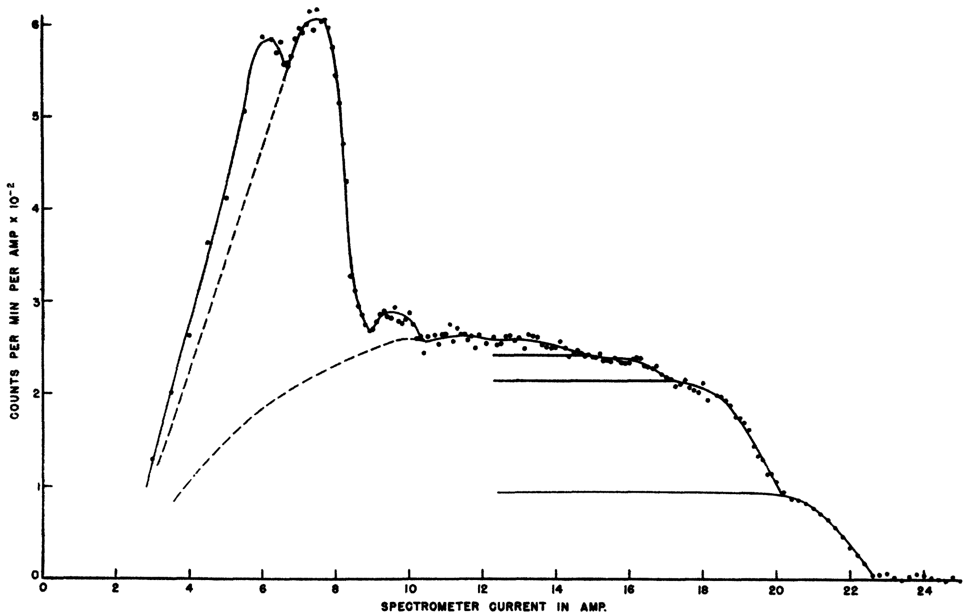

FIG. 5. Electron distribution from Ga^{72} in a bare copper capsule. Each counting rate has been divided by the current to get counts per unit momentum interval.

the Compton counting rate (evaluated in between the photoelectron lines) to about 70 percent of its value with no uranium radiator. Enough points between lines were available to establish the amount to be subtracted to within less than 100 counts per min. from 25 amp to 11 amp and below 6 amp. Since no reference points could be found between 6 and 11 amp, the amount to be subtracted in this region may be off by several hundred counts per minute, particularly below 8.5 amp where the Compton electrons from the strong line at 0.84 Mev become very important.

The data shown in Fig. 4 are fairly conclusive evidence for the existence of the seven lines indicated. It is extremely unlikely that any of these lines could arise from an impurity for the whole curve has been shown to decay with the 14.1 hour half-life of Ga^{72}. Moreover, an examination of a table of the known radioactive elements reveals that none has a half-life, gamma-ray spectrum, activation cross section and probable abundance (as shown by spectroscopic analysis) which could account for these lines.

Further evidence for the existence of these lines and also further information about their relative intensities can be obtained by comparing the electron distribution (chiefly Compton) from Ga^{72} in the bare copper capsule with that of Na^{24} with a 74.9 mg/cm^2 radiator. Figure 5 shows the curve of counts per unit current against current for Ga^{72} in a bare copper capsule. The Compton distributions of the four strongest gamma-rays are clearly evident. The corresponding curve for Na^{24}, Fig. 6, shows that: (1) the Compton distribution from the 2.76 Mev line is horizontal from 22 amp ($\sim$2.3 Mev) to 13 amp ($\sim$1.2 Mev) where it begins to turn downward toward the origin; (2) the height of the Compton distribution at its maximum is roughly proportional to the intensity of the gamma-ray from 22 amp ($\sim$2.3 Mev) at least to 11 amp ($\sim$1.0 Mev). The fact that the Compton distribution from Ga^{72} is not horizontal between 17 amp where it should level off for the 2.21 Mev gamma-ray and 13 amp is strong evidence for the existence of at least two weak gamma-rays in this interval. By comparison with the curve for Na^{24}, the approximate horizontal levels indicated by the curve of Fig. 5 have been drawn in. It should be strongly emphasized that the shape of the steps in Fig. 5 is not justified by the accuracy of the points but is necessitated by the fact that a single gamma-ray can only give a step function with a horizontal or declining top as shown by the curve for Na^{24}. The upward trend between 17 amp and 13

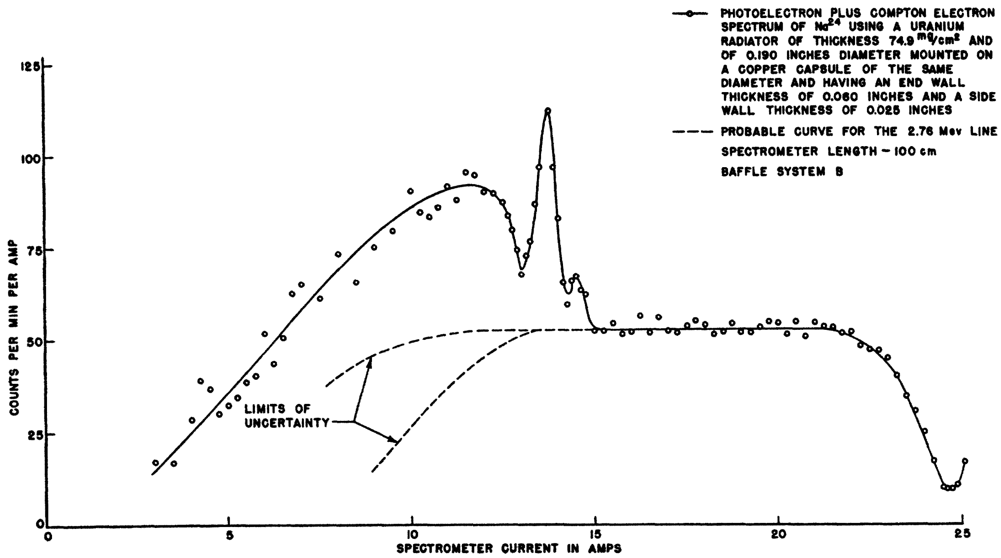

FIG. 6. Photoelectron plus Compton electron spectrum of Na^{24} showing the horizontal top of the Compton distribution from the 2.76 Mev line. Each counting rate has been divided by the current to get counts per unit momentum interval.

amp in Fig. 5 is well outside of experimental error. The energies of the gamma-rays deduced from the Compton end points shown are not very accurate but are in agreement within experimental error with those obtained from the photoelectron lines. The possibility of a very weak additional gamma-ray is indicated by the fact that between 13 amp and 10 amp the curve does not begin to fall as does the sodium curve. The energy of this gamma-ray would be about 1.2 Mev. However, much more data would be necessary to establish its existence beyond doubt. The rounded peak between 9 and 10 amp is attributed in part to the copper photoelectron yield of the strong 0.84 Mev line and to a lesser extent to the Compton distribution of the weak 1.05 Mev line.

In order to separate the lines below one million electron volts, a run was made with the 12.8 mg/cm² thick uranium radiator. The results are shown in Fig. 7 where the background of Compton electrons from the bare copper has been subtracted out. If a photoelectron line exists corresponding to the 0.68 Mev transition observed in the beta-ray spectrum its intensity is probably less than two percent, indicating a minimum conversion coefficient of the order of 25 percent. This photoelectron line would be difficult to detect for it falls very close to the maximum of the Compton distribution of the 0.84 Mev line and not far from the L shell photoelectron line of the 0.63 Mev gamma-ray line. These results are not in contradiction with the hypothesis of a $0 \rightarrow 0$ transition with no parity change since the conversion coefficient may well be 100 percent. When considered in conjunction with its half life $(0.5 \times 10^{-6}$ sec)[16] and energy,

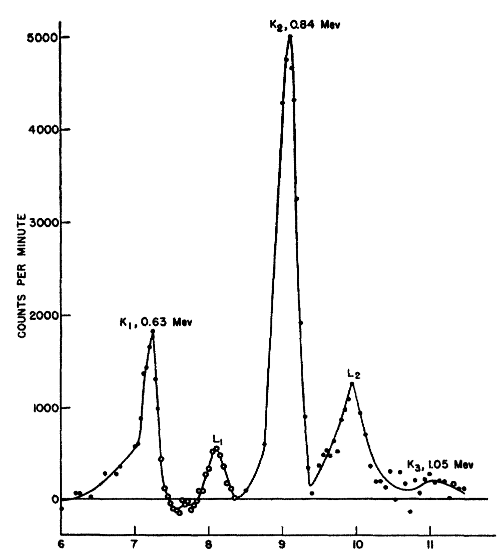

FIG. 7. Photoelectron distribution at low energies with a uranium radiator of thickness 12.8 mg/cm². Open circles represent three times as much data as full black circles.

TABLE I. Gamma-ray intensities of Ga^{72} in percent of the 0.84 Mev line.†

Line	1 Compton	2 Compton*	3 Photo 12.8 mg/cm²	4 Photo 21.9 mg/cm²	5 Photo 42.2 mg/cm²	6 Photo 74.9 mg/cm²	7 Photo 74.9 mg/cm²*	8 Conversion line	9 Average
2.51 Mev	(24)	26.5*		31.5	23	(26.5)	26.5*		26.5±4%*
2.21 Mev		34*					32*		33 ±5%*
1.87 Mev		7.9*					7.6*		7.8±2%*
1.59 Mev		4.5*					4.6*		4.5±2%*
(1.20) Mev?		(<2)*							(<2%)*
1.05 Mev			((4.2))				(4.6)*		(4.5±2%)*
0.84 Mev	100		100	100	100	100			100%
0.68 Mev			(<2)					0.5%	<2%
0.63 Mev	(31)		24			(18.5)			24±5%

† One or more parentheses about a figure indicates one or more known uncertainties in the figure. In averaging, each parentheses reduce the weight of the observation by a factor of 2.
* Figures so denoted are based upon a 26.5 percent intensity of the 2.51 Mev line.

the order of magnitude of the conversion coefficient of this transition eliminates assignment to it of any finite value of Δl.

The energies of the gamma-rays given in Table I were obtained from the complete run with a 74.9 mg/cm² uranium radiator. Corrections of the order of 0.5 percent were subtracted from the several lines of highest energy as a result of analysis of the positions of the photoelectron lines in the following runs: (1) the four calibration runs with annihilation radiation mentioned above, (2) runs with 74.9 mg/cm², 42.2 mg/cm², 21.9 mg/cm² and 12.8 mg/cm² uranium radiators on the 0.84 Mev line, and (3) runs with all but the 12.8 mg/cm² radiator on the 2.51 Mev line.

IV. GAMMA-RAY INTENSITIES OF Ga^{72}

The intensities of the gamma-rays relative to the 0.84 Mev line as 100 percent have been calculated from the photoelectron lines using the semi-empirical formula of Deutsch *et al.*[21]

$$n_p = Ct_r\tau[(kt_r/\beta^3\Delta p)^2+1]^{-\frac{1}{2}} \quad (1)$$

where n_p is the observed line height, t_r is the radiator thickness in g/cm², τ is the photoelectric mass absorption coefficient for the gamma-ray under consideration, β is the velocity of the photoelectron relative to the velocity of light, Δp is the momentum resolution width of the spectrometer, and k and C are empirical constants. The constant k was determined for the 0.84 Mev line and the 2.51 Mev line by use of radiators of several thicknesses.

TABLE II. Beta-ray end point differences in Mev.

Beta-ray	3.15	2.52	1.48	0.955	0.64
3.15	—	0.63*	1.67	2.205*	2.51*
2.52	0.63*	—	1.04*	1.565*	1.88*
1.48	1.67	1.04*	—	0.525	0.84*
0.955	2.205*	1.565*	0.525	—	0.315
0.64	2.51*	1.88*	0.84*	0.315	—

[21] M. Deutsch, L. G. Elliott, and R. D. Evans, Rev. Sci. Inst. 15, 193 (1944).

The intensities have also been calculated from the maximum height of the Compton distribution in accord with observations on Na^{24}. Each of these methods applied respectively to the complete runs with 74.9 mg/cm² U radiator and with no radiator should give the relative intensities of the lines above 1.5 Mev fairly accurately. Neither will give an accurate comparison between this group of lines and the 0.84 Mev line for the following reasons: (1) For the complete photoelectron spectrum with the 74.9 mg/cm² radiator, the height of the photoelectron lines below one Mev is an unreliable index of intensity both because the Compton background is uncertain in this region and because Eq. (1) has not been adequately tested for such a thick radiator in this region. (2) Since no test of the relative heights of Compton distributions with lines of known intensity below one Mev was made with the geometry used in these experiments the maximum heights of the Compton distributions may not be a reliable measure of intensity in this range.

The two runs on the 0.84 Mev and the 2.51 Mev lines with uranium radiators of 42.2 mg/cm² and 21.9 mg/cm² are within the range in which Eq. (1) may be expected to hold. The intensity of the 2.51 Mev line relative to the 0.84 Mev line was chiefly obtained from these two runs with less weight given to the determinations with the 74.9 mg/cm^2 radiator and the relative heights of the Compton distributions as shown in Table I, columns 1, 4, 5, 6, and 9.

Using the value of 26.5 percent for the intensity of the 2.51 Mev line, the intensities of the lines at 2.21 Mev, 1.87 Mev, and 1.59 Mev are readily obtained as shown in columns 2 and 7 of Table I. The excellent agreement in the relative intensities in columns 2 and 7 is very strong evidence for the existence of the lines at 1.87 Mev and 1.59 Mev. The intensity of the 1.05 Mev line cannot be obtained from the Compton distribution because the copper photoelectron yield of the 0.84 Mev line also falls between 9 and 10 amperes. It can be roughly estimated from the runs with the 12.8 mg/cm^2 and 74.9 mg/cm^2 radiators as shown in columns 3 and 7 of Table I. The intensity of the 0.68 Mev line is less than 2 percent as previously discussed and as shown in column 3 of the table. The most accurate value for the intensity of the 0.63 Mev line is that obtained from the 12.8 mg/cm^2 radiator, for with this radiator not only does Eq. (1) hold but the Compton background is observable between lines. Less reliable figures are obtained from the Compton distribution and also from the data taken with the 74.9 mg/cm^2 radiator (previously published).[9]

V. DECAY SCHEME AND DISCUSSION

As stated in Section II the Kurie plot of the beta-ray spectrum can be separated into five linear components with the following end points and intensities: 3.15 Mev (9.5 percent), 2.52 Mev (8 percent), 1.48 Mev (10.5 percent), 0.955 Mev (32 percent), and 0.64 Mev (40 percent). In order to get an indication of the validity of these apparent end points, all possible energy differences between them are taken and compared with the gamma-ray energies (Table II). The differences indicated by an asterisk in Table II correspond closely to gamma-ray energies in Table I. On each line the values to the right of the blank diagonal represent transitions into the state determined by the end point at the left hand end of the line while values to the left of the diagonal represent transitions out of this

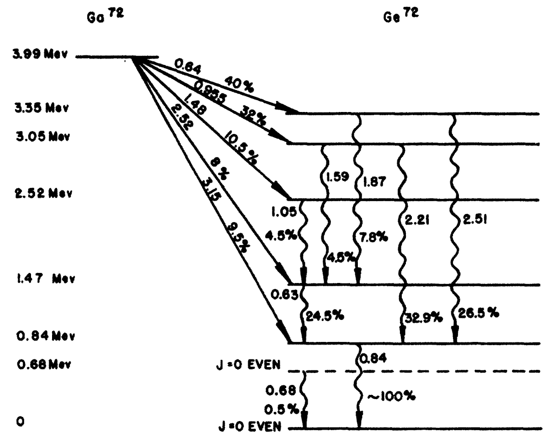

FIG. 8. A nearly complete proposed decay scheme for Ga[72].

state. Every energy of beta-ray has at least two differences associated with it which correspond to gamma-ray energies. Hence, as a preliminary hypothesis, all five beta-ray groups will be assumed to exist.[22]

The difference between the highest and lowest energy beta-ray end points is about 2.5 Mev and since Barker[17] has obtained a figure of 2.6 Mev of gamma-ray energy per beta-particle, it follows that none of the beta-ray groups reported here can go to the ground state of Ge^{72}. As stated above, this inference is also supported by coincidence work.[8,13] The most logical assumption is, therefore, that the very intense 0.84 Mev

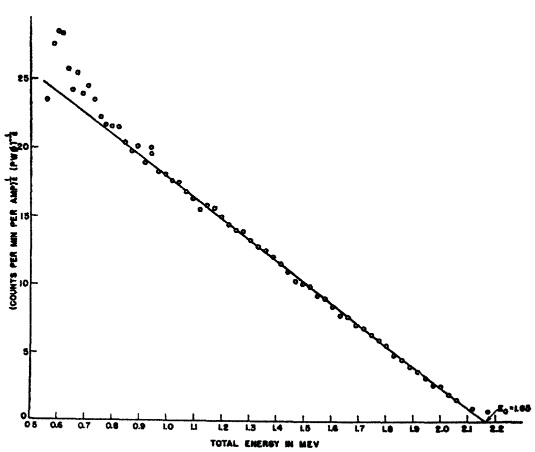

FIG. 9. A Kurie Plot of the Ga[70] beta-ray spectrum.

[22] Further support for the existence of the 1.48 Mev beta-ray group comes by private communication from M. Goldhaber who finds that the beta-rays which precede the 0.68 Mev delayed conversion electrons seem to have an end point at roughly 1.5 Mev. No delayed gamma-rays were found.

gamma-ray is emitted in the transition to the ground state of Ge^{72} for all or nearly all disintegrations. In any case the 0.84 Mev difference in Table II cannot account for the large intensity of the 0.84 Mev line of Table I for the only transition out of the state terminated by the 1.48 Mev beta-ray group is the weak 1.05 Mev gamma-ray.

Using the assumption that the 0.84 Mev line appears in almost all disintegrations, and assuming that all five beta-ray groups exist, the decay scheme shown in Fig. 8 is obtained. In this figure the level differences have been determined by the most accurately known gamma-rays and the intensities of both beta-ray groups and gamma-ray lines are those reported above. The agreement between beta-ray end points and level values is excellent while the agreement between the incoming and outgoing intensities of each state is surprisingly good. It would appear that the 1.48 Mev beta-ray group is not as intense as the linear Kurie-plot would indicate and that some of the beta transitions assigned to this group actually belong to the 3.15 Mev group. Probably some of the transitions assigned by linear Kurie plot to the 0.64 Mev group actually belong to the 0.955 Mev group. The value obtained for the average gamma-ray energy per beta-particle from Table I and Fig. 8 is 2.64 $\pm$0.16 Mev which is in good agreement with Barker's value of 2.6 Mev.[17]

It is probable that the 0.68 Mev conversion line ($0\rightarrow0$ transition)[16] is a transition to the ground state of Ga^{72}, for if the transition were between two high energy levels, one would expect the high energy transitions to the ground state to compete strongly with the 0.68 Mev transition. Further strong evidence that the 0.68 Mev transition terminates in the ground state of Ge^{72} is the fact that no delayed gamma-rays are found.[22] One or more weak gamma-rays of total energy corresponding to the difference of 1.84 Mev between the levels at 2.52 Mev and 0.68 Mev presumably remain to be found.[22] If one such gamma-ray exists, it would be masked by the stronger line at 1.87 Mev. If the 1.2 Mev line of Table I actually exists, an additional weak line between 0.65 and 0.75 Mev probably also is present. Such a line has been reported by Mitchell *et al.*[10]

No coincidence experiments were performed on Ga^{72}. For verification of such a complicated decay scheme, it appears that coincidence experiments involving one or more spectrometers will be necessary. More accurate data on gamma-ray intensities will also be helpful.

VI. BETA-RAY SPECTRUM OF Ga^{70}

In the course of the work on Ga^{72} it was possible to make two 20 minute irradiations of Source *A* and to investigate the beta-ray spectrum of Ga^{70} (20.5 min. half life).[23] After inserting the source in the spectrometer as rapidly as possible, the lens current was varied in steps of 0.25 amp while counts were recorded during 0.5 min at each step. More than one step per minute was made so that the complete spectrum was run in about an hour (three half lives). The spectrum was then rerun in order to establish the amount of 14.1 hour activity to be subtracted out. One run was made from high energy to low and one from low to high. The Kurie plot of the resulting spectrum (Fig. 9) has an end point at 1.65 Mev and is linear down to about 0.4 Mev. Further investigation would be necessary to ascertain whether the deviation from a straight line below 0.4 Mev is due to scattering, another group of beta-rays, or non-linearity of the Kurie plot of the 1.65 Mev beta-ray group. No conversion lines were detected above 0.6 Mev. Below this energy the spacing and accuracy of the experimental points are not sufficient to show conversion lines. No attempt to measure the gamma-ray spectrum of Ga^{70} was made.

VII. ACKNOWLEDGMENTS

The author wishes to express his appreciation to many members of the staff both at Clinton National Laboratory and at Vanderbilt University for their help and advice. Particular recognition is due Dr. A. H. Snell who suggested the problem and whose continued counsel was of very great value. Many helpful discussions were held with Dr. E. Greuling and Mr. P. W. Levy. Special thanks are due to Miss T. Arnette who helped operate the spectrometer and made many calculations.

[23] E. C. Barker, private communication.