APPENDIX

A list of the more important functions encountered in this paper is here appended.

$$S = ZR/a_0,$$
$$\Delta = e^{-S}(1+S+S^2/3),$$
$$B = (Ze^2/a_0)(1+S^{-1})e^{-2S},$$
$$C = \frac{Ze^2}{a_0}\left(S^{-1}+\frac{5}{8}-\frac{3}{4}S-\frac{S^2}{6}\right)e^{-2S},$$
$$T = \frac{Ze^2}{a_0}(1+S)\bigg/\left(1+S+\frac{S^2}{3}\right).$$

X is a more complicated function involving Sugiura's integral. In terms of the functions used and defined in Pauling and Wilson,[21]

$$X = \frac{Ze^2}{a_0}\left(\frac{1}{S}+\frac{2K(S)}{\Delta(S)}+\frac{K'(S)}{\Delta^2(S)}\right).$$

For calculations, the graph of X given in Fig. 4 will be found more convenient.

[21] L. Pauling and E. B. Wilson, fr., *Introduction to Quantum Mechanics* (McGraw-Hill Book Company, New York). See p. 342 et seq.

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The Energies of the γ-Rays from Radioactive Scandium, Gallium, Tungsten, and Lanthanum

C. E. MANDEVILLE*
The Rice Institute, Houston, Texas

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The energies of some γ-rays have been determined by the method of semicircular focusing of Compton recoils in a magnetic spectrograph. The results thus obtained are as follows:

Radioelement	Sc^{48}	Ga^{72}	W^{187}	La^{140}
Quantum energies (Mev)	1.35 ± 0.03	1.17 ± 0.02, 2.65 ± 0.06	0.94 ± 0.02	2.04 ± 0.04

The two quanta emitted in the disintegration of Ga^{72} are present with equal intensity, which suggests that they may be in cascade. The γ-ray activity of Ga^{72} was followed for 100 hours and was found to decay with a half-period of 14.25 ± 0.20 hr.

INTRODUCTION

THE energies of the γ-rays emitted in the disintegration of several radio-elements have been measured by means of a magnetic spectrograph which has been previously described.[1] Compton recoil electrons are focused by a magnetic field, and coincidences are then observed as a function of $H\rho$. The radius of curvature of the path of the recoils is 5.50 cm.

Because of the fact that slow electrons are heavily absorbed and scattered from the focused beam by the walls of the counters and by the argon-alcohol counter mixture which is present throughout the magnet box, it has been found advisable to employ double coincidence counting, using the counters T_1 and T_2 (Fig. 1, reference 1), when making observations on quanta of an energy less than 1 Mev. Triple coincidence counting, with the counters T_1, T_2, and T_3, is especially suitable for obtaining end points of distributions in regions of higher energy (greater than 1 Mev), since the gamma-ray background is then very small. The absorption of the slow electrons also leads to a lower limit of satisfactory measurement. The recoils arising from γ-rays of energy less than about 0.5 Mev are not observable.

The treatment of the background count and the corrections which are applied to data obtained with this spectrograph have been previously outlined[1] and are obviously the same,

*At present at the Radiation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] C. E. Mandeville, Phys. Rev. **62**, 309 (1942); Phys. Rev. **63**, 387 (1943).

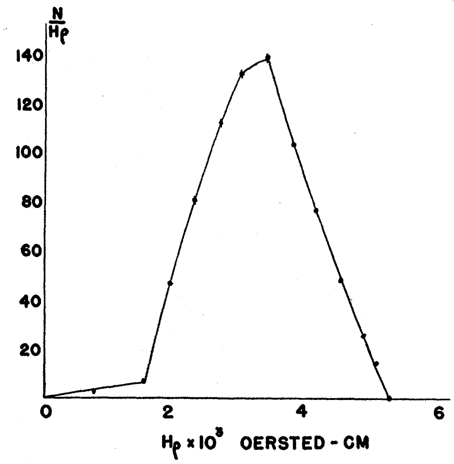

FIG. 1. Momentum distribution of the Compton recoils of the γ-rays from Sc^{48}. The Sc^{48} of this curve was produced by a bombardment of CaF_2 by deuterons of energy 12 Mev. Triple coincidences in the counters T_1, T_2, and T_3 were recorded.

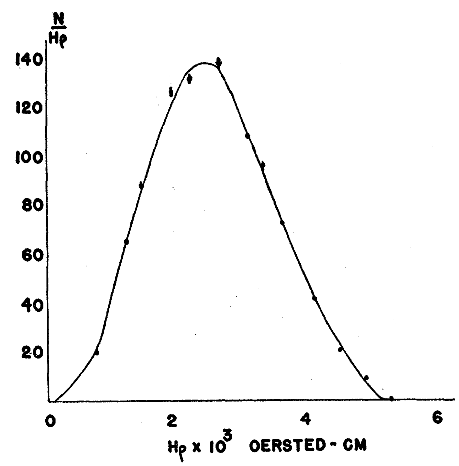

FIG. 2. Momentum distribution of the Compton recoils of the γ-rays from Sc^{48}. The Sc^{48} of this curve was produced by the reaction $Ti^{48}(n,p)Sc^{48}$. Double coincidences in the counters T_1 and T_2 were recorded.

whether double or triple coincidences are recorded.

In all instances under discussion in this paper, observations were begun at a time not less than twenty-four hours after cessation of bombardment.

Sc^{48}

The γ-rays from Sc^{48} have been discussed in a preliminary report.[2] The momentum distribution of the Compton recoils of the γ-rays from Sc^{48} produced by a bombardment of calcium fluoride by deuterons of energy 12 Mev is given in Fig. 1. The energy of the γ-ray taken from the end point of the distribution is found to be 1.35 ± 0.03 Mev. The ordinates of the distribution were found to decay with the established 44-hr. half-period[3] of Sc^{48}. In obtaining the curve of Fig. 1, triple coincidences were recorded. The electrons of low energy are seen to be heavily absorbed on the interval $0 < H\rho < 2000$.

Pure titanium dioxide was bombarded by fast neutrons from the reaction *Be–d–n*. The momentum distribution of the Compton recoils of the γ-rays from Sc^{48} formed by the reaction $Ti^{48}(n,p)Sc^{48}$ is given in Fig. 2. The quantum energy obtained from the end point of the distribution is again found to be 1.35 ± 0.03 Mev. Double coincidences were recorded.

Hibdon, Pool, and Kurbatov[4] have likewise found Sc^{48} to be a gamma-ray emitter, and their absorption experiments indicate a quantum energy of 1.33 Mev.

Ga^{72}

Pure metallic gallium has been irradiated by slow neutrons. The γ-ray activity was followed

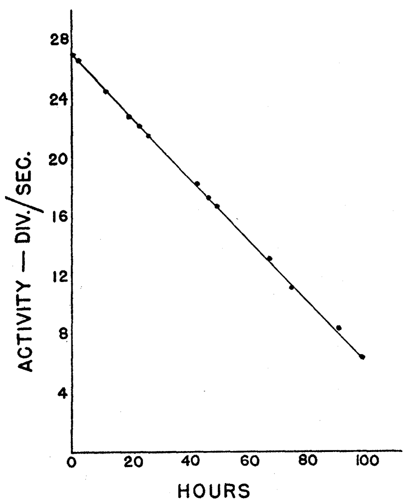

FIG. 3. Decay of gamma-ray activity of Ga^{72}. The half-period taken from the slope of the curve is 14.25 ± 0.20 hr.

[2] C. E. Mandeville, Phys. Rev. **62**, 555 (1942).
[3] H. Walke, Phys. Rev. **57**, 163 (1940).
[4] C. T. Hibdon, M. L. Pool, and J. D. Kurbatov, Phys. Rev. **63**, 462 (1943).

for one hundred hours with a Lauritsen electroscope, and the half-period taken from the slope of the decay curve of Fig. 3 was found to be 14.25±0.20 hours, in good agreement with the value 14.1±0.2 hr. obtained by Sagane.[5] The momentum distribution of the Compton recoils of the γ-rays from Ga^{72} is given in Fig. 4, where it is seen that two quanta of energies 1.17±0.02 Mev and 2.65±0.06 Mev are emitted with equal intensity, suggesting that they may be in cascade.

It is of interest to note that Sagane *et al.*,[6] using cloud chamber and magnetic field, have found the K–U extrapolated limit of the β-rays from the negatron emitting Ga^{72} to be 1.71 Mev, whereas absorption experiments by Livingood and Seaborg[7] have indicated a maximum β-ray energy of 2.6 Mev. The disagreement between the two results might be related to secondary effects arising from the 2.65 Mev γ-ray from Ga^{72}. The influence of Compton recoils from γ-rays of high energy upon absorption measurements of the energies of primary β-rays has been discussed in several recent publications.[8-10]

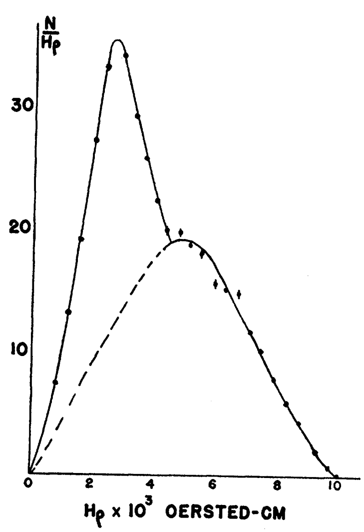

FIG. 4. Momentum distribution of the Compton recoils of the γ-rays from Ga^{72}. The two electron groups correspond to two equally intense quanta having energies of 1.17±0.02 Mev and 2.65±0.06 Mev.

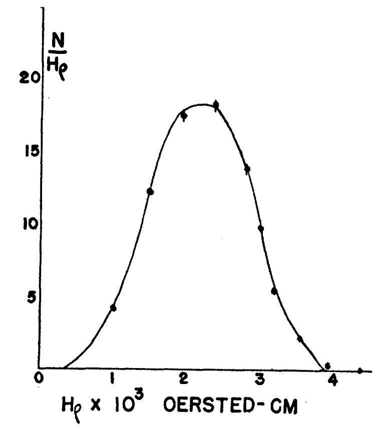

FIG. 5. Momentum distribution of the Compton recoils of the γ-rays from W^{187}.

W^{187}

The radioactive tungsten isotope of half-period 24.1 hours[11] was produced when pure powdered tungsten was irradiated by slow neutrons. The momentum distribution of the Compton recoils of the γ-rays from W^{187} is given in Fig. 5. The quantum energy as determined from the end point of the distribution was found to be 0.94 ±0.02 Mev. The energy of this γ-ray has been previously reported to be 0.87±0.03 Mev by lead absorption,[11] and aluminum absorption of the Compton recoils of this γ-ray has led to a quantum energy of 0.90 Mev.[12] From the shape of the curve of Fig. 5, it is clear that the γ-ray of energy 0.94 Mev is the only γ-ray present with an energy greater than 0.5 Mev.

Evidence for the emission by W^{187} of γ-rays of an energy less than 0.5 Mev has also been obtained.[12, 13]

La^{140}

The γ-rays emitted by the 40-hr.[14] La^{140} have been discussed in a previous report.[1] The γ-ray activity of pure La_2O_3 irradiated by slow neutrons was followed for 160 hours and was found to decay with a half-period of 40.8±1.0 hr. The decay curve is given in Fig. 6. The momentum

[5] R. Sagane, Phys. Rev. **55**, 31 (1939).
[6] R. Sagane, 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] M. Deutsch, Phys. Rev. **61**, 672 (1941).
[9] M. Deutsch, J. R. Downing, L. G. Elliot, J. W. Irvine, Jr., and A. Roberts, Phys. Rev. **62**, 3 (1942).
[10] Lise Meitner, Phys. Rev. **63**, 73 (1943).
[11] Kasimir Fajans and W. H. Sullivan, Phys. Rev. **58**, 276 (1940).
[12] Arnold F. Clark, Phys. Rev. **61**, 242 (1942).
[13] G. E. Valley, Phys. Rev. **59**, 686 (1941).
[14] K. E. Weimer, M. L. Pool, and J. D. Kurbatov, Phys. Rev. **63**, 67 (1943).

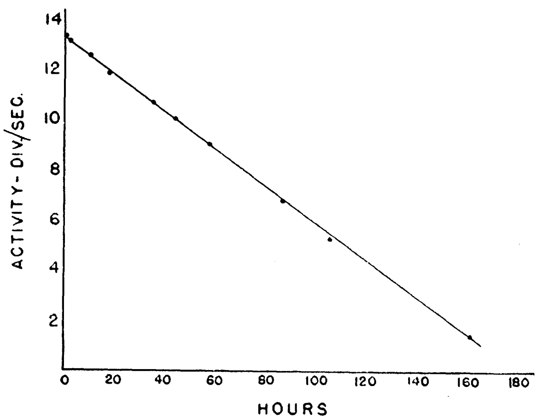

FIG. 6. Decay of gamma-ray activity of La_2O_3 irradiated by slow neutrons. The half-period taken from the slope of the curve is 40.8 ± 1.0 hr.

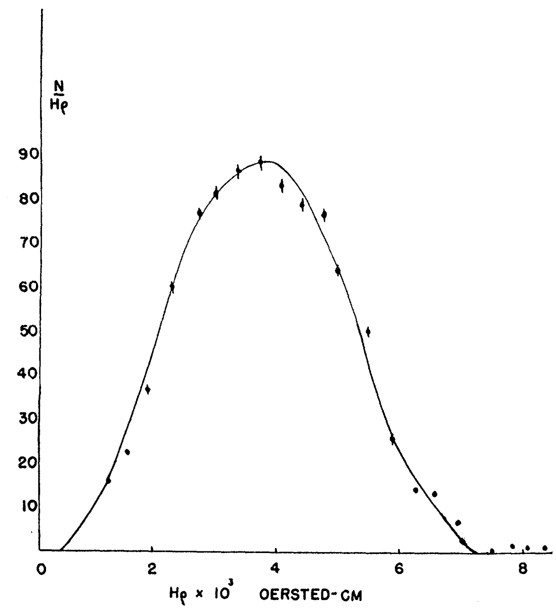

FIG. 7. Momentum distribution of the Compton recoils of the γ-rays from La^{140}.

distribution of the Compton recoils of the γ-rays from La^{140} is to be seen in Fig. 7, and the quantum energy of the single γ-ray present was found to be 2.04 ± 0.04 Mev, in good agreement with the previously determined absorption value of 2.00 ±0.05 Mev.[14]

It is not as yet certain whether La^{140} may be regarded as a source of absolutely monochromatic 2.04-Mev radiation, since recent coincidence experiments[15] by W. C. Peacock of The Massachusetts Institute of Technology seem to indicate that a γ-ray of energy less than 0.3 Mev is in cascade with the 2.04-Mev quantum. These coincidence experiments were only of a preliminary nature, however, and are not yet to be regarded as conclusive.

OTHER REMARKS

Sc^{48} and La^{140} appear to be, for the most part, emitters of monochromatic gamma-radiation. It is suggested, therefore, that the γ-rays of these elements might be used for the determination of the exact shape of the momentum distribution of the Compton recoils of a single γ-ray at the outset of experiments in which spectrographs of this type or related types are employed. A knowledge of the shape of the distribution arising from a single γ-ray is particularly desirable, since a misunderstanding of the nature of the distribution may lead to an erroneous interpretation of results obtained from an examination of emitters of complex gamma-ray spectra.[1]

ACKNOWLEDGMENTS

The writer wishes to point with emphasis to the fact that the radioactive isotopes discussed in this paper were without exception prepared by the members of the cyclotron group of Washington University, St. Louis, Missouri. The splendid cooperation of Professor A. L. Hughes, Mr. H. W. Fulbright, and other members of the Washington University cyclotron group made possible these investigations.

The writer wishes also to acknowledge the kind interest and advice of Professor H. A. Wilson of the Rice Institute.

[15] M. Deutsch, private communication.