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Gamma-Rays from Na^{24}

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A gamma-ray spectrograph of high resolving power has been employed in measuring the quantum energies and relative intensities of the gamma-rays from Na^{24}. The energies thus determined are 0.84, 1.31, 1.66, and 2.90 Mev with relative intensities 0.28, 0.41, 0.45, and 1.00. These results indicate excitation levels in the Mg^{24} residual nucleus at 1.3, 2.9, and 3.7 Mev in partial agreement with experiments on proton scattering by magnesium, but in disagreement with the level schemes suggested by previous gamma-ray measurements.

Measurements were also made on the gamma-radiation of the thorium active deposit. Close agreement with previous results was considered adequate confirmation of the calibration of the spectrograph.

INTRODUCTION

THE energies and relative intensities of the gamma-rays emitted from Na^{24} have been studied by several investigators.[1–7] Their results do not agree very well, and the presence of gamma-radiation in the neighborhood of 2 Mev has been in dispute. This paper contains an account of new measurements of these gamma-ray energies and intensities, and a level scheme for Mg^{24} is suggested. The gamma-rays from Th(C′+C″) have also been observed as a check on the accuracy of the method.

THE SPECTROGRAPH

The energies of the Compton recoil electrons arising from gamma-rays were measured by semicircular focusing in a magnetic field. A diagram of the spectrograph is shown in Fig. 1. It is very similar to that described by Curran, Dee, and Strothers.[5] The depth of the magnet box is 3 cm, and its inside diameter is 18 cm. Compton electrons are ejected from the bottom of the cup C and in order to be counted must follow a circular path of radius 5.50 cm. The cup is so inclined that the electrons counted emerge at an angle of about 20° with the bottom of the cup, thus making the effective width of the source small. The Geiger-Mueller counters T_1, T_2, T_3 and the entire box are filled with an argon-alcohol mixture at 10 cm Hg, the ratio of the partial pressures being about 9 : 1. The counters are 2.0 cm long and are mounted in holes which are bored in a block of Lucite. Their diameters are 1.0, 1.5, and 2.0 cm, respectively. Triple coincidences are recorded. The copper cases, of thicknesses 0.001 cm, are contiguous but the wire potentials are independently variable. The varying diameters allow for divergence of the beam of electrons after the focusing at the slit S_1, just beneath the counters. The width of this slit is about 3.0 mm. The sides of this slit are strips of brass 2 cm in length, 1 cm in width, and sufficiently thick to stop an electron of 5-Mev energy, thus preventing the counting of particles not focused on the slit proper. Three other aluminum slits S_2, S_3, and S_4 are also placed

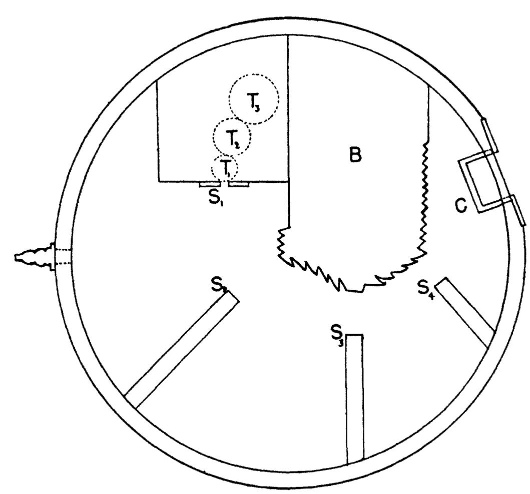

FIG. 1. The spectrograph.

[1] J. Reginald Richardson and F. N. D. Kurie, Phys. Rev. **50**, 999 (1936).
[2] J. Reginald Richardson, Phys. Rev. **53**, 124 (1938).
[3] S. Kikuchi, Y. Watase, J. Itoh, E. Takeda, and S. Yamaguchi, Proc. Phys. Math. Soc. Japan **21**, 260 (1939).
[4] S. Kikuchi, Y. Watase, J. Itoh, E. Takeda, and S. Yamaguchi, Proc. Phys. Math. Soc. Japan **21**, 381 (1939).
[5] S. C. Curran, P. I. Dee, and J. E. Strothers, Proc. Roy. Soc. **A175**, 546 (1940).
[6] J. Itoh, Proc. Phys. Math. Soc. Japan **23**, 605 (1941).
[7] L. G. Elliot, M. Deutsch, and A. Roberts, Phys. Rev. **61**, 99 (1942).

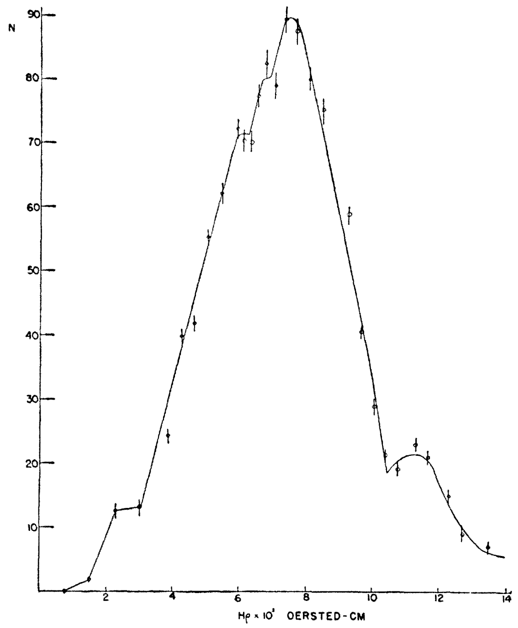

FIG. 2. Intensity N, of Compton recoils from gamma-rays from Th(C′+C″) as a function of $H\rho$.

in the box for collimating purposes. The center slit S_3, the defining one, is 1.8 cm wide, and the lower edge is 5.3 cm above the bottom of the box, thus making recesses into which electrons not entering the counters may drop. The lead block B employed to shield the counters from gamma-rays coming directly from the source, is 5.8 cm in thickness. The $H\rho$ spread allowed by the source width and the slit system is estimated to be about 5 percent. The maximum measurable kinetic energy which a beta-particle may have in the field of the Weiss magnet used is about 12 Mev. A typical Rossi circuit and the usual recording meter and thyratron were employed in counting the triple coincidences.

The background of the counters was found to be constant for both Th(C′+C″) and Na^{24} over a wide $H\rho$ interval above the end point of the hardest gamma-ray measured in each case. This background was also equal to the background at $H\rho=0$. The background at intermediate points was therefore obtained by extrapolation. Since the background was small as compared to the total number of counts observed, any error in calculation of the relative intensities introduced by this procedure would be small.

There are four factors for which corrections

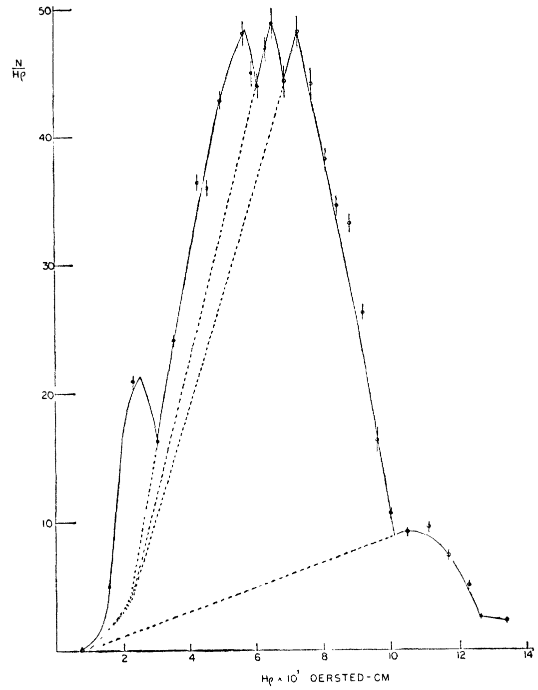

FIG. 3. Momentum distribution of Compton recoils of gamma-rays from Th(C′+C″).

must be made: (1) increase with increasing H of the value of the $H\rho$ interval over which electrons are counted, (2) variation of the Compton scattering coefficient with energy, (3) dependence of the emission of an electron upon its range in the thick aluminum target, (4) variation with energy of the absorption of electrons in the walls of the counters. This last correction is small for electron energies greater than 1 Mev. Plotting $N/H\rho$ against $H\rho$ serves as a correction for (1). Factors (2) and (3) complicate the determination of the relative intensities of the various components of the gamma-ray spectra. They may be most satisfactorily dealt with, however, by evaluating the relative intensities with the equation

$$\text{Rel. Int.} = \frac{\text{Area under } N/H\rho \text{ plot}}{(\text{electron range in Al})(\text{Compton coeff.})}.$$

A rough correction for (4) is obtained from known absorption curves.[8]

TABLE I. Gamma-rays from Th(C′+C″).

Energy in Mev	0.73±.02	1.58±.03	1.77±.04	2.66±.05	3.32±.10
Rel. Int.	0.14	0.10	0.05	1.00	0.09

[8] E. Madgwick, Proc. Camb. Phil. Soc. 23, 970 (1927).

Th(C′+C″)

Figure 2 is a plot of N against $H\rho$ and Fig. 3 one of $N/H\rho$ against $H\rho$. The peaks of the outstanding components of the gamma-ray spectrum are clearly evident in the latter case. Their energies and relative intensities are given in Table I. Ellis[9] has reported gamma-rays from Th(C′+C″) at 1.63, 1.80, and 2.62 Mev with intensities 0.08, 0.04, and 1.00. Weak gamma-rays of quantum energy about 3.3 Mev have been reported by several authors. The intensity reported here is somewhat higher than the most recent report by Itoh and Watase.[10] The intensity of the 0.73 Mev quantum agrees closely with that given by these authors.[10]

The clearly separated peaks of the gamma-rays at 1.58 and 1.77 Mev demonstrate the high resolving power of the spectrograph. The sharp rise to a peak and the equally sharp drop to a clearly defined end point from which the gamma-ray energy may be obtained is to be expected with a spectrograph of this type from the nature of the Compton process. It is further interesting to note the shape of the peaks of the gamma-rays of lower quantum energy and lower intensity in the neighborhood of the intense 2.66-Mev peak. This graph is very useful in analyzing the curves obtained from other radioactive sources.

RADIO-SODIUM

The gamma-rays of Na^{24} were initially investigated by Richardson and Kurie,[1] and again by Richardson,[2] the expansion chamber and magnetic field being employed in both instances. Quantum energies of 1.01, 2.04, and 3.00 Mev were reported, and the intensities of the two softer components were estimated to be about equal. Since the sum of their energies was approximately equal to the energy of the third component, it was assumed that levels of 2 and 3 Mev or 1 and 3 Mev existed in the Mg^{24} product nucleus.

TABLE II. Gamma-rays from Na^{24}.

Energy in Mev	0.84±.02	1.31±.03	1.66±.03	2.90±.06
Rel. Int.	0.28	0.41	0.45	1.00

[9] C. D. Ellis, Rep. Internat. Conf. on Phys. (London, 1934).

[10] J. Itoh and Y. Watase, Proc. Phys. Math. Soc. Japan **23**, 142 (1941).

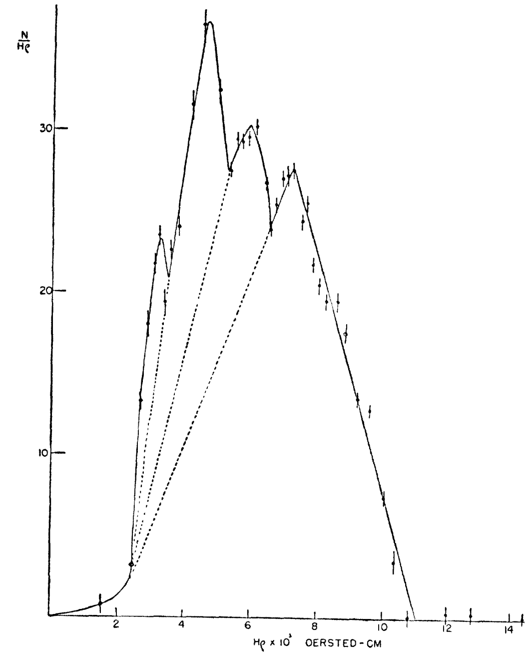

FIG. 4. Momentum distribution of Compton recoils of gamma-rays from Na^{24}.

Upon the suggestion of Feather and Dunworth,[11] this level scheme was revised, the new assumptions being that gamma-rays of 1 and 3 Mev were emitted in cascade and two rays of quantum energies about 2 Mev were also emitted in a cascade process. Kikuchi *et al.*[3] reported gamma-rays of about equal intensities with quantum energies 1.49±.05 and 2.97±.07 Mev, thus establishing the 4-Mev level suggested by Feather and Dunworth at 4.46 Mev. Later work by Kikuchi *et al.*[4] resulted in the values 1.55±.05 and 2.97±.05 Mev. In both experiments, weak radiation at about 0.8 Mev was also observed.

Curran, Dee, and Strothers[5] have reported the energies 1.46, 2.00, and 3.03 Mev with relative intensities 1.17, 0.27, and 1.00. The most recent measurements[6,7] have given indication of only two gamma-rays, having energies 1.38±.02 and about 2.80 Mev. These latter authors may have failed to detect any other radiation because of low intensities.

In this experiment, a sodium chloride crystal, activated by a bombardment of several hours by a deuteron current of 0.3 microampere at 2 million volts, was used as a source, the half-life

[11] N. Feather and J. V. Dunworth, Proc. Camb. Phil. Soc. **34**, 442 (1938).

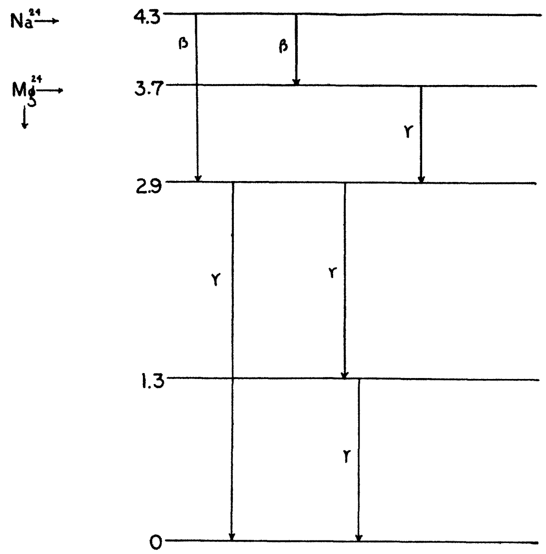

FIG. 5. Level scheme for Mg^{24}.

being 14.8 hr. Radio-chlorine of 37-min. half-life is formed from the deuteron bombardment of Cl^{37} (relative abundance 25 percent). Although the Cl-*d*-*p* reaction is known to be very small as compared to the Na-*d*-*p* reaction at this voltage, and although measurements were not made until after any radio-chlorine present had decayed by about 5 half-periods, a potassium chloride crystal was bombarded under the same conditions for the sake of comparison. Contributions from radio-chlorine were found to lie well within the statistical probable error of the points of the curve for Na^{24}. Above $H\rho=4000$, about 800 coincidences were counted at each point. Below that value of $H\rho$ about 550 coincidences were recorded at each point.

The curve for Na^{24}, $N/H\rho$ against $H\rho$, obtained with the spectrograph just described, is shown in Fig. 4. The results are tabulated in Table II.

These quantum energies and relative intensities suggest that de-excitation of the Mg^{24} nucleus after beta-emission by Na^{24} may occur with the emission of a single quantum of energy about 2.90 Mev or with the emission of quanta of energies 1.66 and 1.31 Mev in cascade. It would seem then that the disintegration energy of Na^{24} is 1 Mev less than that suggested by Feather and Dunworth.[11] The level scheme is similar to that initially suggested by Richardson and Kurie,[1] though theirs was based upon different quantum energies.

The quantum of energy 0.84 Mev is probably the weak line first observed by Kikuchi *et al.*,[3,4] and is, as they have pointed out, indicative of the emission of a complex beta-ray spectrum by Na^{24}, contrary to the results of Feather and Dunworth[11] and of Lawson,[12] who found the beta-ray spectrum to be simple and of maximum energy 1.4 Mev. The results of Table II indicate that the soft component of the beta-ray spectrum is about one-fifth as probable as the more intense distribution of higher maximum energy. A complete level scheme is given in Fig. 5. By means of experiments on the inelastic scattering of protons by magnesium, Wilkins[13] has assigned excitation energies to Mg^{24} of 1.37, 2.80, and 4.07 Mev in partial agreement with the results reported in this paper.

It seems possible that other investigators have over-estimated the intensity of the gamma-ray at 1.31 Mev because of insufficient resolution and the unsuspected presence of the gamma-ray at 1.66 Mev. Attributing all of the areas of the 0.84- and 1.31-Mev quanta and about one-half the area of the 1.66-Mev quantum to a hypothetical gamma-ray of energy about 1.45 Mev, and applying all corrections for that energy, an intensity about equal to that of the 2.90-Mev quantum is obtained, thus offering a possible explanation for previous interpretations.

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[12] J. L. Lawson, Phys. Rev. **55**, 131 (1939).
[13] T. R. Wilkins, Phys. Rev. **60**, 365 (1941).
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