find that the photo-fission cross section of bismuth is at least 10^3 times smaller than the cross section of uranium.

It would be interesting to investigate the resonance scattering of photons by the dipole vibration. The value of $\int \sigma_{scatt} d\omega$ for this process should be a considerable fraction of the theoretical value derived above for the absorption cross section. The resonance scattering will be, therefore, comparable in intensity to the Compton scattering. The two kinds of scattering processes can be distinguished by their angular dependence. The Compton scattering will be observed in the forward direction. The resonance scattering has, in the first approximation, an intensity proportional to $\sin^2\vartheta$, where ϑ is the angle included by the direction of the scattered radiation and the polarization direction of the primary γ-ray. Deviations from the $\sin^2\vartheta$ law are to be expected due to the finite radius of the nucleus. The scattered radiation may turn out to be a good source of fairly monochromatic γ-rays. The investigation of the spectrum of these scattered rays may open a convenient way to study the breadth of the resonance, while a detailed study of the angular distribution may yield information about the current distribution in the dipole vibration.

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Coincidence Experiments on Sc^{46}, Ga^{72}, Au^{198}, and Rb^{86}

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Gamma-gamma- and beta-gamma-coincidences have been investigated in the disintegration of the active isotopes Sc^{46}, Ga^{72}, Au^{198}, and Rb^{86}. Gamma-gamma-correlation was found in Sc^{46} and in Ga^{72} but not in Au^{198} or Rb^{86}. The beta-ray spectra of Sc^{46} and Au^{198} are found to be simple on the basis of beta-gamma-coincidence measurements, while those of Ga^{72} and Rb^{86} are complex. Gamma-ray energies and beta-ray maximum energies were determined by absorption methods.

I. INTRODUCTION

COINCIDENCE experiments, as described by Mitchell,[1] frequently are a great aid in establishing decay schemes for radioactive isotopes. Experiments on the radiations from Sc^{46}, Ga^{72}, Au^{198}, and Rb^{86} have been done, and the results are to be reported herein. The coincidence amplifier, which has a resolving time of about two microseconds, and its associated counting apparatus have been described previously.[2]

II. SCANDIUM 46

Peacock and Wilkinson[3] have measured the energies of the beta- and gamma-rays from Sc^{46} with a 180°-type magnetic spectrometer and find gamma-ray energies of 0.89 Mev and 1.12 Mev and beta-ray groups with end-point energies of 0.36 Mev and 1.49 Mev, with the 1.49 Mev beta-ray group very weak.

A source was prepared on the Indiana University cyclotron according to the reaction $Sc^{45}(d,p)Sc^{46}$, and the resulting Sc^{46} was purified chemically. Two silver-cathode glass counters were arranged with thick aluminum radiators to obtain gamma-gamma-coincidences. For the particular geometrical arrangement which was used, the ratio of the gamma-gamma-coincidence rate to the rate of counting gamma-rays in one of the counters was measured to be $(0.72\pm0.08)\times10^{-3}$. From this it can be concluded that cascaded gamma-rays occur in the disintegration.

Figure 1 shows that the ratio of the beta-gamma-coincidence rate to the beta-ray counting rate is independent of the thickness of absorber

[1] A. C. G. Mitchell, Rev. Mod. Phys. **20**, 296 (1948).
[2] E. T. Jurney and A. C. G. Mitchell, Phys. Rev. **73**, 1153 (1948).
[3] C. L. Peacock and R. G. Wilkinson, Phys. Rev. **74**, 297 (1948).

placed between the source and the counter up to thicknesses around 0.06 g/cm², which is only a little less than the thickness required to absorb completely the 0.36 Mev group. One concludes that the low-energy group is followed by at least one gamma-ray. The intensity of the high energy group reported by Peacock and Wilkinson is so low that it cannot be detected by absorption methods; it is clearly impossible, then, to measure the ratio $N_{\beta\gamma}/N_\beta$ for this group.

The results described here are in good agreement with those obtained by Mandeville and Scherb[4] and also are compatible with the disintegration scheme proposed by Peacock and Wilkinson.

III. GALLIUM 72

The method of coincidence counting has been used with Ga^{72} by Mitchell, Jurney, and Ramsey[5] and by Mandeville and Scherb.[6] These two investigations yielded results which were in very close agreement, namely, that the beta-ray spectrum consists of two groups, with the low energy group having an end point somewhat under 1 Mev. A more careful investigation than the one reported by Mitchell, Jurney, and Ramsey has recently been made here. Again gamma-gamma-coincidences were observed, which indicate the presence of cascaded gamma-rays in the disintegration. Figure 2 shows the result of the beta-gamma-coincidence measurements; the beta-ray spectrum is seen to be complex, with an inner end point in the neighborhood of 0.38 g/cm² or 0.92 Mev, according to the Feather range-energy relation.

Mitchell, Zaffarano, and Kern[7] have proposed a disintegration scheme for Ga^{72} based on measurements made with a magnetic lens spectrometer, in which there are seven possible excited levels in the resulting Ge^{72} nucleus. In their scheme roughly three-quarters of the transitions from Ga^{72} involve beta-ray groups having end-point energies of 1.0, 0.74, and 0.56 Mev. The remaining transitions to Ge^{72} are through one of four relatively weak groups, the most energetic of which has an end point at 3.17 Mev. One would expect the ratio $N_{\beta\gamma}/N_\beta$ to increase slowly from an absorber thickness corresponding to this energy to a thickness corresponding to about 1 Mev, according to this scheme, and to increase much more rapidly from there up to zero thickness. The counting errors are too large to determine the slope of the curve in the 1–3 Mev region; Mandeville and Scherb's curve appears to indicate a dependence of $N_{\beta\gamma}/N_\beta$ on the absorber thickness there, however. Coincidence methods cannot be expected to confirm completely such a complex scheme as Mitchell, Kern, and Zaffarano's, but the results here are not in disagreement with their scheme.

IV. GOLD 198

Clark,[8] Norling,[9] and Mandeville and Scherb[10] have performed experiments on Au^{198} which

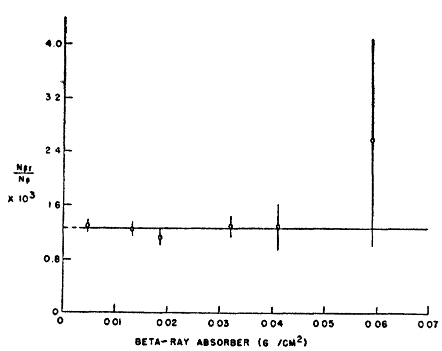

FIG. 1. Beta-gamma-coincidences in Sc^{46}.

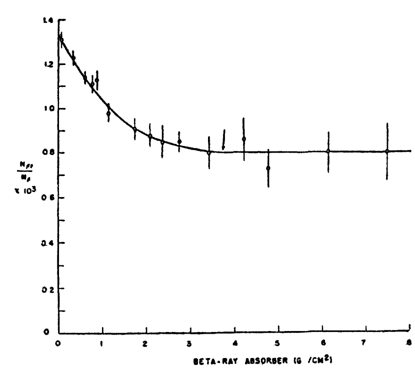

FIG. 2. Beta-gamma-coincidences in Ga^{72}.

[4] C. E. Mandeville and M. V. Scherb, Phys. Rev. **73**, 141 (1948).
[5] A. C. G. Mitchell, E. T. Jurney, and M. Ramsey, Phys. Rev. **71**, 324 (1947).
[6] C. E. Mandeville and M. V. Scherb, Phys. Rev. **72**, 520 (1947).
[7] A. C. G. Mitchell, D. J. Zaffarano, and B. D. Kern, Phys. Rev. **73**, 1424 (1948).
[8] A. F. Clark, Phys. Rev. **61**, 242 (1942).
[9] F. Norling, Arkiv. f. Mat. Ast. Och Fys. **B27** (3), 4 (1941).
[10] C. E. Mandeville and M. V. Scherb, Phys. Rev. **73**, 634 (1948).

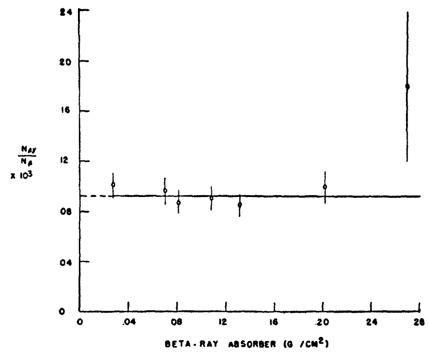

FIG. 3. Beta-gamma-coincidences in Au^{198}.

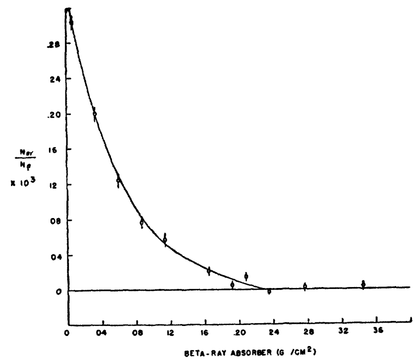

FIG. 4. Beta-gamma-coincidences in Rb^{86}.

give a value of $N_{\beta\gamma}/N_\beta$ which is independent of beta-ray absorber thickness. These authors disagree, however, in that Clark and Mandeville and Scherb find gamma-gamma-coincidences while Norling does not. The findings of Clark and of Mandeville and Scherb are supported by the spectrographic measurements of Levy and Greuling[11] in which gamma-rays of 0.157, 0.208, and 0.408 Mev were detected. Measurements by Siegbahn[12] and by Peacock and Wilkinson[3] fail to show more than one gamma-ray occurring in the disintegration.

A preliminary investigation here[13] yielded a value of $N_{\gamma\gamma}/N_\gamma = (-0.038 \pm 0.02) \times 10^{-3}$ for Au^{198}. The counters which were used for that measurement had lead cathodes to improve the sensitivity for counting gamma-rays. Absorption of low-energy gamma-rays by the counter walls was rather high, although the 0.157 and 0.208 Mev lines reported by Levy and Greuling still would reach the counter gas with 25 percent and 42 percent of their initial respective intensities.

Recently another attempt has been made to find gamma-gamma-coincidences. Two silver cathode glass counters were arranged 6.3 cm apart with the source midway between them. Each counter was shielded from the source by a 0.4 cm thickness of aluminum. Using an unpurified source which was prepared according to $Au^{197}(n,\gamma)Au^{198}$ a value of $N_{\gamma\gamma}/N_\gamma = (0.043 \pm 0.012) \times 10^{-3}$ was found. The experiment was then repeated, with the same geometry, but with a source which had been given chemical separation from possible mercury contamination, and a value of $N_{\gamma\gamma}/N_\gamma = (0.022 \pm 0.01) \times 10^{-3}$ was found. This small value is not interpreted as being significant, especially since no particular pains were taken to prevent coincidences arising from scattering.

The gamma-gamma-correlation found by Clark was very low, and might be ascribed to a small amount of contamination of his source by some other active isotope, as he does not indicate that his source had been given any chemical purification after bombardment. The gamma-gamma-coincidence rate found by Mandeville and Scherb might also be due to an impurity, especially if their pile irradiation was a long one.

Figure 3 gives the ratio $N_{\beta\gamma}/N_\beta$ as a function of beta-ray absorber thickness, of which it is seen to be independent. This indicates a simple beta-ray spectrum and is in agreement with the results of Clark, Norling, and Mandeville and Scherb.

From the results here one would conclude that Au^{198} disintegrates by the emission of a single beta-ray, and that the resulting excited Hg^{198} nucleus reaches its ground state by the emission of a single gamma-ray.

V. RUBIDIUM 86

A source of Rb^{86} was produced by neutron irradiation in the Clinton pile and was separated from cesium in an ion exchange column. The absorption of the beta-rays in aluminum was determined, and the resulting data were analyzed by the method proposed by Bleuler and Zünti,[14] which showed beta-ray groups with end points

[11] P. W. Levy and E. Greuling, Phys. Rev. **73**, 83 (1948).
[12] K. Siegbahn, Proc. Roy. Soc. **189**, 527 (1947).
[13] E. T. Jurney and M. R. Keck, Phys. Rev. **73**, 1220 (1948).
[14] E. Bleuler and W. Zünti, Helv. Phys. Acta **19**, 375 (1946).

at 1.82 Mev (~67 percent) and 0.56 Mev (~33 percent). The maximum gamma-ray energy was found to be 1.12 Mev by coincidence absorption of Compton recoil electrons produced in an aluminum target.

Figure 4 shows the result of beta-gamma-coincidence measurements. It is evident that no coincidences are present for beta-ray absorption thicknesses greater than 0.23 g/cm^2 of aluminum, which corresponds to 0.62 Mev. Hence the transitions which involve the 1.76 Mev beta-ray group lead directly to the ground state of Sr^{86}. Those coincidences which appear between this absorber thickness and zero absorber thickness are to be ascribed to disintegrations which involve the low-energy beta-ray group. No evidence of gamma-gamma-coincidence could be found; it is to be concluded that the low energy group of beta-rays leads to a 1.12 Mev level of Sr^{86}, which in turn goes to the ground state with the emission of a single gamma-ray.

The spectrum of Rb^{86} has recently been measured in a magnetic lens by Zaffarano, Kern, and Mitchell,[15] who found one gamma-ray of energy 1.081 Mev and two beta-ray groups with end points at 1.822 and 0.716 Mev. The results described in the present paper confirm their results.

VI. ACKNOWLEDGMENTS

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[15] D. J. Zaffarano, B. D. Kern, and A. C. G. Mitchell, Phys. Rev. **74**, 682 (1948).

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Additional Rotational Energy Levels of H_2O and D_2O Molecules*

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An extension of the pure rotational energy levels for H_2O and D_2O is made in order to obtain new possible microwave transitions. For H_2O the levels are given through $J=14$ and for D_2O through $J=15$. Additional assignments are made in the previously observed absorption spectra. The Wang secular determinant for the asymmetric rotator is expanded, and equations for the the energy levels of $J=12$, 13, 14, and 15 are given in terms of the asymmetry parameter.

INTRODUCTION

THE calculation by Van Vleck[1] on the absorption of microwaves by water vapor showed an absorption greater than the amount predicted by the theory as developed. An effort to account for the residual absorption on the basis of line widths was unsuccessful. It was thought that the additional intensity might be accounted for by an accidental coincidence with a line corresponding to a transition value between levels of J higher than 11. The absorption spectrum of water vapor had previously been observed and analyzed by several investigators, the most satisfactory and complete analysis being that of Randall, Dennison, Ginsburg, and Weber[2] (hereafter referred to as RDGW). They obtained the pure rotational spectrum in the region from 140 to 555 cm^{-1} and combined their results with those of Wright and Randall[3] in the longer wave-

* The calculations and energy levels for H_2O were presented at the Symposium on Molecular Structure and Spectroscopy, Ohio State University, Columbus, Ohio (June, 1947).

[1] J. H. Van Vleck, Phys. Rev. **71**, 425 (1947).

[2] Randall, Dennison, Ginsburg, and Weber, Phys. Rev. **52**, 160 (1937).

[3] N. Wright and H. M. Randall, Phys. Rev. **44**, 39 (1933).