RESULTS

The data have not been subjected to any corrections. The error estimated for the measurement of the beam current was 1 percent. The geometry measurement was good to $\frac{1}{2}$ percent. The concentration of tritium molecules in the gas sample could be estimated to 2 percent. In other experiments using the chamber, 3 percent to 5 percent corrections were necessary to correct the test p-p and p-He^4 scattering data to agree with published results. It was not felt that any correction could be made with confidence on the reaction data. For these reasons an estimated error of ± 8 percent is attached to the results.

Figure 3 and Table I show the cross sections for the production of alpha-particles as a function of alpha-particle angle in the center-of-mass system of coordinates. The indicated errors are, in the main, determined by the average deviation from the mean of the several runs at a given angle. The results are in general agreement with the Los Alamos data but do not seem to indicate so strong a tendency for the alpha-particle to come off in the forward direction.

We wish to thank Professor J. H. Williams for suggesting this problem and for his interest and advice during the experiment. We also wish to thank the members of the electrostatic generator group for their cooperation in obtaining these data.

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Nuclear Spectroscopy of Ba^{131}

M. W. Elliott, L. S. Cheng, J. R. Haskins, and J. D. Kurbatov
Physics Department, Ohio State University, Columbus, Ohio

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The spectra of Ba^{131} have been investigated in permanent magnet spectrographs, a solenoidal beta-spectrometer and a thin lens gamma-spectrometer. Gamma-rays of 122, 214, 241, 370, and 494 kev have been confirmed. In the conversion electron spectrum, there is indication of the existence of three low energy gamma-rays: ~65 kev, ~43 kev, and ~108 kev. The K/L ratios, K-conversion coefficients and relative intensities have been estimated.

I. INTRODUCTION

SEVERAL studies have been made on the energies, relative intensities, conversion coefficients, and multipole orders for the gamma-rays emitted by Ba^{131}.[1-6] Gamma-rays with energies of 122, 196, 206, 213, 241, 371, and 496 have been reported,[5,6] but there is disagreement as to their relative intensities and as to which of those around 200 kev are present. This investigation has therefore been undertaken to check and extend the results which have to date been presented.

II. APPARATUS AND PROCEDURE

Permanent magnet semicircular spectrographs, a solenoidal beta-spectrometer and a thin lens gamma-spectrometer were employed for the studies of the conversion electron spectrum and the photoelectron spectrum of Ba^{131}. The two spectrographs (low and high energy) were calibrated with I^{131}. Resolution of about 1 percent can be expected for gamma-rays of 100 kev or higher. The solenoidal spectrometer, which was used to study the conversion electrons, was equipped with a thin-window counter tube which transmitted electrons down to 17 kev. From 17 kev to 45 kev window correction was carried out on the peak height of conversion electrons. The instrument was calibrated with I^{131} and Cs^{137}. Its resolution setting was 1.5 percent. The thin lens spectrometer was used to study the photoelectron spectrum. It was calibrated with I^{131} diluted with common barium such that the geometries of the two samples, Ba^{131} and I^{131} plus Ba, were made substantially identical. The resolution setting was 2.5 percent.

The activity in the form of barium nitrate, pile activated, was obtained from Oak Ridge National Laboratory. Three samples were made. The one for the spectrographs was prepared by placing Ba^{131} on cellulose tape. Because of the low specific activity, a thick sample was required. The sample for the conversion electron spectrum was approximately 8 mm in diameter and 8 mg/cm^2 thick. It was covered with 0.2 mg/cm^2 zapon film. The sample for the photoelectron spectrum was large, having a cylindrical volume of about 1.8 cc and a diameter of 1.7 cm.

The conversion electron spectrum was measured several times so that decay would discriminate the peaks belonging to different radioactive isotopes of barium.

The photoelectron spectrum was measured with a 30 mg/cm^2 lead radiator and with a 21 mg/cm^2 ura-

[1] Yu, Gideon, and Kurbatov, Phys. Rev. **71**, 382 (1947).
[2] S. Katcoff, Phys. Rev. **72**, 1160 (1947).
[3] Dale, Rickert, Redfield, and Kurbatov, Phys. Rev. **80**, 763 (1950).
[4] Zimmermann, Dale, Thomas, and Kurbatov, Phys. Rev. **80**, 908 (1950).
[5] E. Kondaiah, Ark. fys. **2**, 295 (1950).
[6] R. Canada and A. B. Mitchell, Phys. Rev. **83**, 76 (1951).

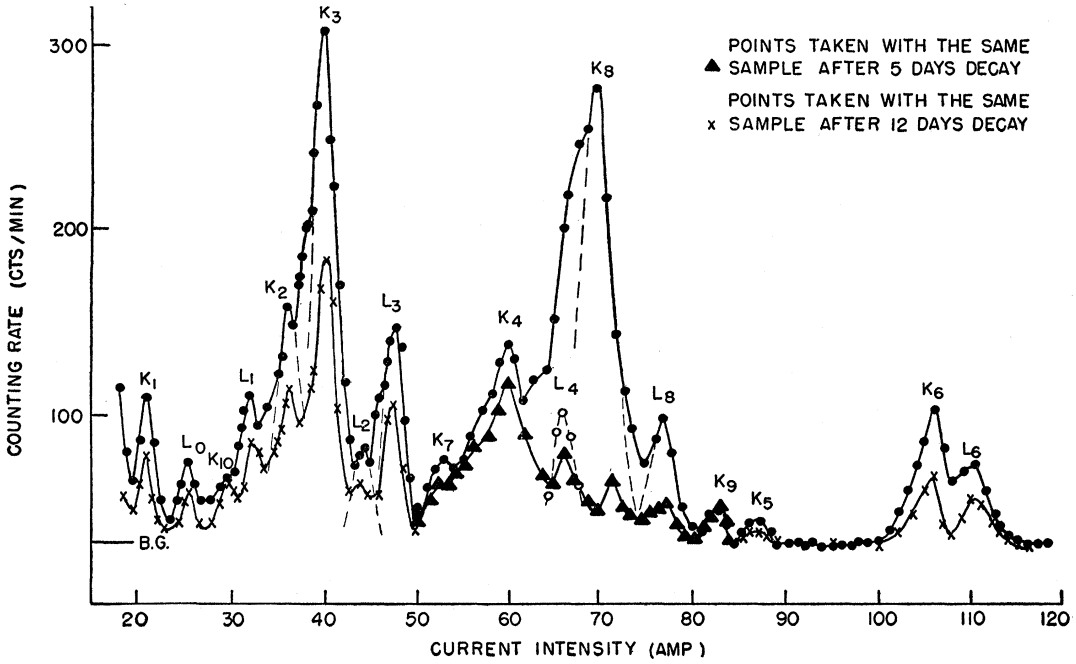

FIG. 1. Conversion electron spectrum of $Ba^{131,133,135}$.

nium radiator. The two radiators were used so that peaks possibly superimposed using one might be separated using the other.

III. CONVERSION ELECTRON SPECTRUM

Figure 1 shows the plot of counting rate against current, for the conversion electrons. The lower curve lying between 50 amp and 85 amp was obtained 5 days after the upper curve. It reveals, in addition to the K- and L-conversion electron peaks of the 214-kev gamma-ray of Ba^{131} (K_4 and L_4 in Fig. 1), the 270-kev gamma-ray emitted by 29 hr Ba^{135m} (K_8 and L_8)[7] and the 340-kev gamma-ray emitted by long-lived Ba^{133} (K_9).[8] The peaks K_4 and L_4 decay with half-life of about 12 days.

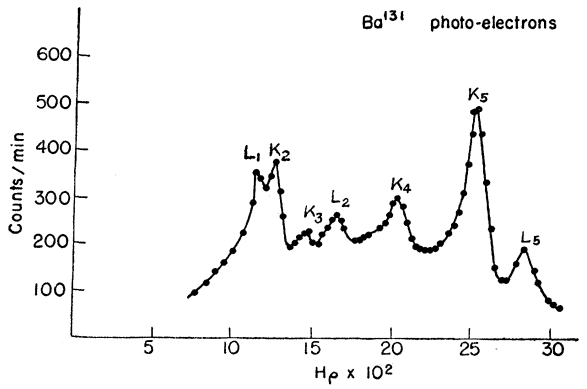

FIG. 2. Photoelectron spectrum Ba^{131} with 30 mg/cm² Pb radiator. Spectrometer set for 3.4 percent resolution.

[7] R. D. Hill and F. R. Metzger, Phys. Rev. 83, 455 (1951).
[8] F. C. Yu and J. D. Kurbatov, Phys. Rev. 74, 34 (1948).

A small impurity (K_7) with a half-life of approximately 3 days, and having conversion electrons with kinetic energy of about 142 kev, cannot be identified.

The lower curve between 19 amp and 50 amp was measured 12 days after the upper curve. All peaks, except the peak K_{10}, decay with a half-life of about 12 days, so they are assigned to Ba^{131}. The peaks K_3 and L_3 belong to the highly converted 122-kev gamma-ray of Ba^{131}. In addition there is indicated the existence of three low energy gamma-rays: ~65 kev (K_1 and L_1), ~43 kev (L_0) and ~108 kev (K_2 and L_2). The peak K_{10} was first revealed in the second run and remained practically of the same intensity in the subsequent runs. It may be identified as the 85-kev gamma-ray emitted by long-lived Ba^{133}.[8]

The lower curve between 85 amp and 120 amp was measured 12 days after the upper curve. The three peaks showed about 12 days half-life. The peaks K_6 and L_6 are the K- and L-conversion peaks of the 494-kev gamma-ray. The peak K_5 is the K-conversion peak of the 370-kev gamma-ray.

Conversion electrons for the following energies of gamma-rays were observed in the permanent magnet spectrographs: K- and L-conversion lines for 122 kev, K- and L-lines for 214 kev, K-line for 241 kev, K- and L-lines for 370, and K-line for 494 kev.

The K/L ratios have been estimated by comparing the areas under K- and L-peaks in a plot of counting rate per unit momentum against momentum. Source thickness correction was applied as the result of data obtained from the conversion peaks of thin (carrier-free) and thick (common cerium added to ~10 mg/cm²) Ce^{144} samples.

TABLE I. Gamma-rays emitted by Ba^{131}.

Conversion electrons				Photoelectrons							Multipole order	
Solenoidal spectrometer		Permanent magnet spectrograph		Thin lens spectrometer								
				Lead radiator		Uranium radiator						
Energy of gamma-ray (kev)	Peak obs.	Energy of gamma-ray (kev)	Peak obs.	Energy of gamma-ray (kev)	Peak obs.	Energy of gamma-ray (kev)	Peak obs.	K/L	α_K	Relative intensity	by K/L	by α_K
~43	L											
~65	K, L							~3.5			$E1$	
~108	K, L							~7			$M1$	
124±1	K, L	122±1	K, L	122±1	L	122±1	L	6.0±0.5			$M2$	
214±2.5	K, L	214±2.5	K, L	214±2	K, L	216±2	K, L	2.8±0.4	~0.18	0.10	$E2$	$E2$
		244±2.5	K	244±3	K	239±3	K			0.04		
368±4	K	370±4	K, L	370±4	K	372±4	K		~0.010	0.07		$E1$
491±5	K, L	496±5	K	496±5	K, L	494±5	K, L	2.5±0.8	~0.0045	1.00	$E3$	$E2$

IV. PHOTOELECTRON SPECTRA

Figure 2 shows the photoelectron peaks obtained using a 30 mg/cm² lead radiator. The peaks are: the L photopeak of the 122-kev gamma-ray (L_1 in Fig. 2), the K- and L-peaks of the 214-kev gamma-ray (K_2 and L_2), the K-peak of the 241-kev gamma-ray (K_3), the K-peak of the 370-kev gamma-ray (K_4) and the K- and L-peaks of the 494-kev gamma-ray (K_5 and L_5). No K- or L-peak for the reported 196-kev gamma-ray[6] was observed. Its K-peak, however, would be super-imposed with the L-peak of the 122-kev gamma-ray when a lead radiator is used. When a uranium radiator is used, the K-peak of a 196-kev gamma-ray would be sufficiently separated from other peaks to be resolved.

Figure 3 shows the photoelectron spectrum obtained using a 21 mg/cm² uranium radiator. The photopeaks observed are: the L-peak of the 122-kev gamma-ray (L_1 in Fig. 3) superimposed on the K-peak of the 214-kev gamma-ray (K_2), the L-peak of the 214-kev gamma-ray (L_2), the K-peak of the 241-kev gamma-ray (K_3), the K-peak of the 370-kev gamma-ray (K_4), and the K- and L-peaks of the 494-kev gamma-ray (K_5 and L_5).

K-electron internal conversion coefficients have been estimated by comparison with data obtained from an I^{131} sample diluted with common barium to approximately the same geometry as the Ba^{131} photoelectron sample. The 364-kev gamma-ray with $\alpha_K=0.02$ was used as a standard for this comparison.

Relative intensities were also estimated. Photoelectron efficiency corrections were made using Gray's formula.[9]

V. SUMMARY

The results are summarized in Table I. Gamma-rays of 43, 65, 108, 122, 214, 241, 370, and 494 kev have been assigned to Ba^{131}, although it is noted that the three lowest energy gamma-rays were observed only by conversion electrons in the solenoidal spectrometer and thus evidence for their existence or correct energy is not conclusive.

[9] L. H. Gray, Proc. Cambridge Phil. Soc. **27**, 103 (1931).

The K-conversion coefficient for the 122-kev gamma-ray was not estimated, nor was its relative intensity, since the thickness of the counter tube in the thin lens spectrometer precluded observation of the K-photoelectron peak for this gamma-ray. The L-photoelectron peak and the conversion peaks of the 122-kev gamma-ray indicate that it is highly converted.

The multipole assignments were made using the empirical curves for K/L ratio of Goldhaber and Sunyar[10]

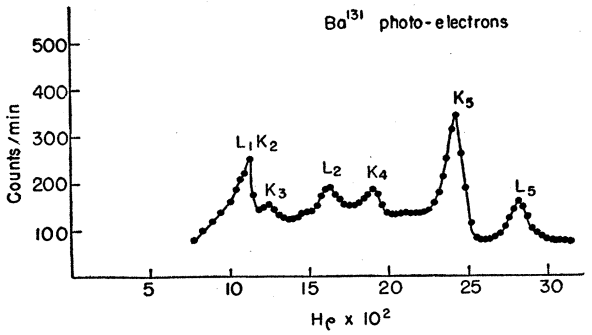

FIG. 3. Photoelectron spectrum Ba^{131}. 0.5-mil uranium radiator. Spectrometer resolution set for 2.4 percent.

and the tables of K-conversion coefficients of Rose *et al.*[11] The multipole orders assigned by these two methods are in conflict for the 494-kev gamma-ray. (An explanation of this discrepancy has not been found by review of experimental work. Further investigation to resolve this conflict is not anticipated unless an enriched isotope becomes available.)

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[10] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[11] Rose, Goertzel, and Perry, Oak Ridge National Laboratory Report No. 1023 (1951) [unpublished].