Energy Quanta Emitted in Disintegration of Ground State of Ba^{133}

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(Received March 19, 1948)

The ground state of radioactive Ba^{133} was correlated with metastable state of Ba^{133*}. It was found that after K-electron capture occurs, there are two excited states in Cs^{133*} corresponding to observed two photons of 320 ± 10 kev and 85 ± 5 kev. Both gamma-rays are converted. The conversion ratios for these two photons are $N_e/N_\gamma\approx0.02$ and ≈0.34, respectively. The change in angular momenta of the excited states of Cs^{133*} due to emission of 320-kev and 85-kev photons is calculated to be $L=2$ and $L=1$. Attempts to observe a third gamma-ray of ~405 kev did not yield positive results. The calculated intensity of the 405-kev photon, if it is emitted, is estimated as equal to 0.001 of the intensity of the 320-kev photon.

1. INTRODUCTION

THE scheme of disintegration of the species Ba^{133} has been investigated by several authors. In the past Ba^{133} was obtained by $(d,2n)$ or (p,n) reactions of cesium. This mode of activation always produced a period of about 39 hours, which was followed by partially converted quanta of 276.4 kev and by K, L, M, x-rays of barium.[1] In accord with these observations, this period has been described as one of the excited states of radioactive Ba^{133}.

Concerning the scheme of disintegration of the ground state of Ba^{133}, the available information is not in sufficient agreement. In older work[1] it was suggested that the ground state of Ba^{133}, of half-life $T\sim340$ hours, disintegrates into stable cesium by K-electron capture followed by K x-radiation of cesium and soft gamma-rays of 17 kev. In more recent works[2–4] the latter was not confirmed.

It was proposed[2] that Ba^{133}, obtained by activation with slow neutrons, disintegrates by K-electron capture, its half-life exceeding 20 years, and leads to the excited state of Cs^{133*}. The latter emits a single photon of 360 kev into the ground state of Cs^{133}.

Independently, observations have been made by other authors that by activation of barium with slow neutrons in a cyclotron the (n,γ) reaction yields a period of $T\sim30$ hours accompanied by quanta of ~250 kev.[3] The 30-hour period in barium has been verified by (d,p) reaction on barium.[4] However, due to the existence of the 39-hour period in Ba, the 30-hour period with close photon energy was mistaken for the 39-hr. Ba^{133*}. Only the 39-hr. period of Ba^{133*} is listed at present in all tables of radioactive species.

2. EXPERIMENTAL RESULTS

In the present study, the radioactive species of barium were obtained by prolonged activation of barium with slow neutrons, and by activation of cesium and of barium with deuterons.

The prolonged activation of barium with slow neutrons yielded after chemical purification several periods in barium that were identified as follows: $T=29$ hr.; $T=39$ hr.; $T=12$ days, and a long period. After 200 days the activated barium was used for studying the radiations of the long period.

The cesium was twice removed from barium in an interval of fifteen days, and since in both separations no activity in the cesium fraction was observed, it was confirmed that Ba^{133} cannot be the mother substance of Cs^{131}, $T=10$ days.

In spite of the low specific activity of barium activated with slow neutrons, it was possible, by means of absorption measurements with a Wulf electrometer, to establish two gamma-rays of ~310 kev and ~80 kev. The same energy values were obtained by using copper and tin absorbers. In Fig. 1 are shown the results on absorption in lead of the radiations from Ba^{133} and for purpose of comparison from Ba^{133*},

[1] J. M. Cork and Gail P. Smith, Phys. Rev. **60**, 480 (1941).
[2] Seymour Katcoff, Phys. Rev. **72**, 1160 (1947).
[3] D. C. Kalbfell and R. A. Cooley, Phys. Rev. **58**, 81 (1940).
[4] K. E. Weimer, M. L. Pool, and J. D. Kurbatov, Phys. Rev. **63**, 59A (1943).

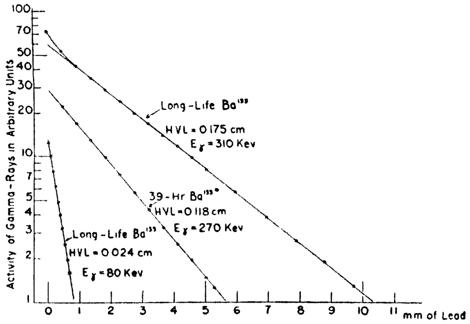

FIG. 1. Lead absorption showing gamma-rays of 270 kev in the 39-hr. period and gamma-rays of 80 kev and 310 kev in the long-life period.

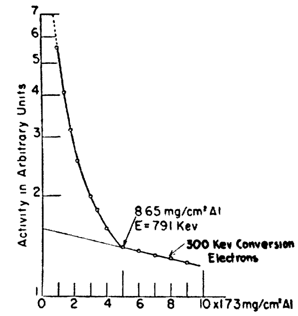

FIG. 2. Long-life Ba^{133}. Absorption of low energy electrons in aluminum.

$T=38.9$ hr. (since the exact energy of 276.4 kev has been established by the beta-spectrometer for Ba^{133*}). The metastable state of Ba^{133*} was secured by the activation of cesium, Cs^{133}, with deuterons.

The low specific activity of Ba^{133} produced by slow neutrons prohibited the use of a spectrometer; consequently, parallel to adsorption a study of Ba^{133} was made in a cloud chamber. The results obtained with the cloud chamber confirmed the existence of two photons from Ba^{133}. In addition, it was possible to obtain a ratio of photo-electron tracks of the photons of ~ 310 kev and of ~ 80 kev. A full account of the work with the cloud chamber will be presented later.

Independently, it has been found that the total ionization current produced in an electrometer by electrons and by photons is predominantly due to the conversion electrons of ~ 80-kev photons. This made it possible to obtain information on the conversion coefficient of the 80-kev photon in K and L shells and to evaluate more exactly its energy as 85 ± 5 kev. In Fig. 2 are given the results of absorption of electrons in aluminum, where there is a sudden change of slope in the curve between the L shell conversion electrons of 85 kev and conversion electrons of 310 kev. A more exact absorption curve of conversion electrons is given in Fig. 3. From this curve, it was possible to estimate the conversion ratio in L and K shells of 85-kev photon. The value of N_K/N_L was found to be between 9 and 11. Making use of the curve given by Hebb and Nelsen, the ratio $N_K/N_L=9$ was obtained which corresponds to one unit change in angular momentum. For an angular momentum change of two units[5] the ratio N_K/N_L would drop to a value of 3.

The K-conversion coefficient was calculated for the 85-kev photon of cesium. It was found that $\alpha_K=0.306$; then $\alpha_K+\alpha_L=0.34$ or $N_e/N_\gamma=0.34$. It can be noted that in case $L=2$, $\alpha_K \sim 2$, which is not consistent with experimental observation.

In order to establish the mass number of the long-life barium and to evaluate better the energy of the photons emitted, a strong activation of cesium was made with deuterons. The barium fraction was separated from the activated cesium without the addition of carrier, that is, all barium atoms produced by (d,n) and $(d,2n)$ reactions were undiluted by common barium or any other carrier.[6]

By following the disintegration of gamma-rays of 276.4 kev, emitted by the 38.9-hr. period, it was established that the photon intensity of the long-life barium was rising (see Fig. 4). The

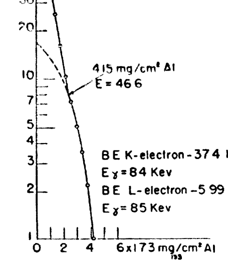

FIG. 3. Long-life Ba^{133} absorption of low energy electrons in aluminum.

[5] M. H. Hebb and E. Nelsen, Phys. Rev. **58**, 486 (1940), S. M. Dancoff and P. Morrison, Phys. Rev. **55**, 122 (1939).
[6] M. H. Kurbatov, Fu-Chun Yu, and J. D. Kurbatov, Chem. Phys. **16**, 87 (1948).

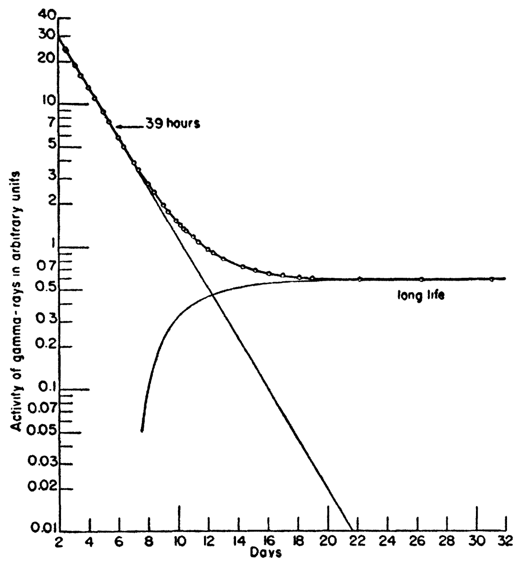

FIG. 4. The genetic relation between the gamma-ray of 276 kev of 38.9-hr. period of Ba^{133*} and that of 320 kev of the long-life Ba^{133}.

energies of the photons of long-life barium have been determined to be equal to 330 kev and 80 kev. In this case a very high specific activity was measured. The energies of conversion electrons corresponding to these two photons were found to be equal to 300 kev and 79 kev for the L shell conversion. Thus it has been determined that the long-life period of barium, obtained by prolonged activation with slow neutrons on barium, possesses the same energy photons as the long-life period in barium, that was obtained by activation of cesium. Therefore, the genetic relation between the metastable state of the 38.9-hr. period Ba^{133*} and the long-life Ba^{133} has been established.

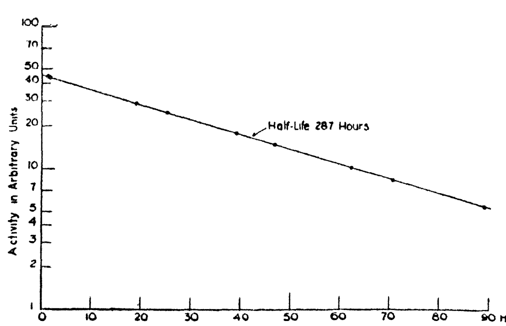

FIG. 5. Decay of Ba^{135*} half-life 28.7 hr., produced by $Ba(d,p)$ reaction.

For the purpose of calibration the ratio of ionization current produced by conversion electrons to the gamma-rays of 276 kev of the 38.9-hr. period was determined as equal to 270. Since the total conversion coefficient N_e/N_e+N_γ for 276-kev gamma-rays is known to be $=0.71$ or $N_e/N_\gamma=2.45$, the efficiency of electrons in producing an ionization current, under the conditions used, is 110 times that of photons.

The calculation of α_K has been made for 38.9-hr. period of Ba^{133*}. It was found that $N_e/N_\gamma=2.32$, taking the change in angular momentum as four. Thus, the calculated value is in good agreement with the experimentally observed $N_e/N_\gamma=2.45$.

The current produced in the ionization chamber (at the same geometry) by conversion electrons of 330-kev gamma-ray was found to be about twice as much as the current produced by the gamma-ray itself. The efficiency of electrons of 300 kev in producing ionization current in the electrometer is approximated as 100 times that of gamma-rays of the same energy. Thus the ratio $N_e/N_\gamma=0.02$ was obtained. The calculated conversion ratios $\alpha_K=N_K/N_\gamma$ for different values of change in angular momenta, L, are:

if $\alpha_K=$	0.0060,	0.019,	0.051,	0.13,	0.33,
$L=$	1,	2,	3,	4,	5.

Therefore, it is reasonable to assume that the change in angular momentum, associated with a photon of 330 kev is two units.

In addition to the activities described above in Ba^{133}, the period of 28.7 hr. was confirmed in barium. The activation of barium with deuterons in a cyclotron resulted in no observation of the 38.9-hr. period of Ba^{133}. In contrast, the period of 28.7 hr. was clearly defined (see Fig. 5). Due

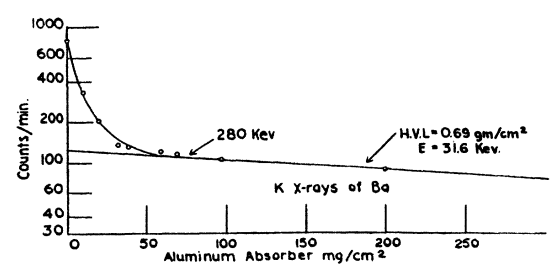

FIG. 6. Aluminum absorption of conversion electrons of 28.7-hr. period Ba^{135}.

to very intense radiation of the short period of Ba^{139}, $T=86$ min., the study of the 28.7-hr. period was limited to the determination of monochromatic electron energy, which proved to be 280 kev, and to the determination of K x-rays of barium (see Fig. 6). Gamma-rays of very weak intensity were also found. Due to the existence of x-ray of barium, of monochromatic electrons, and other experimental observations previously reported,[4] it is postulated that this period is a metastable state of Ba^{135}. However, other assignments of mass number are not entirely eliminated.

3. DISCUSSION OF RESULTS

The ratio of the number of conversion electrons to the number of quanta for 85-kev photon of Ba^{133*} was found to be 0.34, that for 320 kev, 0.02; it can be approximated that the ratio of the number of 320-kev gamma-quanta to 85-kev gamma-quanta is $1.34/1.02=1.31$. These two gamma-rays are assumed to be emitted in cascade. The following experimental evidence has been obtained to this effect. The ratio of the ionization current produced by the 320 kev to that of 85-kev photon was 2.5; this, after correction for efficiency due to the geometry of sample, seems to be in fair agreement with the above. The cloud-chamber data showed that the ratio of the number of conversion electron tracks corresponding to the 85-kev photon to the conversion electron tracks of 320-kev photons is less than twenty.

The spin of the ground state of cesium[7] is given as 7/2; the change in angular momenta of 85-kev photon and 320-kev photon are estimated to be one and two, respectively. Thus, the transition from the excited state of 405 kev above the ground level may be accompanied by a total change in angular momentum from 1/2 to 7/2, or alternately from 13/2 to 7/2. The attempt to observe experimentally a third gamma-ray of 405 kev resulted negatively. This may undermine the possible alternate total change in angular momenta from 9/2 to 7/2, since in this case the emission of photon of 405 kev becomes highly probable.

Calculations were made for the probability of emission of photons of 85 kev, 320 kev, and 405 kev. The results obtained were $T=3.2\times10^{-17}$ sec.; $T=3.8\times10^{-15}$ sec., and $T=6.0\times10^{-12}$ sec., respectively. Therefore, it can be estimated that the intensity of 405-kev photon is about 0.001 of the intensity of 320-kev photon.

The chemical separation of cesium from long-life barium made within a few minutes did not yield any gamma-rays in the cesium fraction; this is accepted as a confirmation of the non-existence of a metastable state in cesium. The critical absorption of x-rays emitted by the long life barium gave consistent results of K x-rays of cesium.

ACKNOWLEDGMENT

The help received from the Alumni Fund of The Ohio State University in securing research equipment is deeply appreciated by the authors. One of the authors is greatly indebted to The Industrial Research Foundation of The Ohio State University for the grant of a fellowship.

We thank the Isotopes Research Division of the U. S. Atomic Energy Commission for neutron activation.

[7] H. Kopfermann, *Kernmoments* (Akademiche Verlagsgesellschaff, Leipzig, 1940).