

in dilute HCl; 8-hydroxyquinoline precipitation at  $pH \sim 5$  with Be and phosphate hold-back carriers; precipitation of  $Fe(OH)_3$  in 0.1N NaOH;  $NH_4OH$  precipitation at  $pH \sim 6$ ; and ignition to  $Al_2O_3$  ("Al<sub>Y</sub>"). After weighing and counting it was put through the same cycle plus a  $LaF_3$  precipitation in dilute HCl, and again weighted and counted ("Al<sub>Z</sub>").

Beta activities were measured with a mica-window Geiger counter at a counting yield of 0.2 count/disintegration. Gamma activities were measured with a NaI(Tl) scintillation spectrometer, all pulses above  $\sim 0.25$  Mev being counted. The results are summarized in Table I. The constancy of the specific activity

TABLE I. Activity of successively purified aluminum samples.

Sample	Al <sub>X</sub>	Al <sub>Y</sub>	Al <sub>Z</sub>
Wt. $Al_2O_3$ (mg)	38.6	29.0	16.0
$\beta$ activity <sup>a</sup> (counts/min)	$26.4 \pm 1.2$	$19.7 \pm 1.3$	$10.3 \pm 1.4$
$\gamma$ activity <sup>a</sup> (counts/min)	$14.5 \pm 1.5$	$> 9.1 \pm 1.0^b$	$4.5 \pm 1.2$
Spec. $\beta$ activity <sup>a</sup> (counts/min mg)	$0.68 \pm 0.03$	$0.68 \pm 0.04$	$0.64 \pm 0.09$
Spec. $\gamma$ activity <sup>a</sup> (counts/min mg)	$0.38 \pm 0.04$	$> 0.31 \pm 0.03^b$	$0.28 \pm 0.08$

<sup>a</sup> Precision indices are standard deviations calculated from counting statistics only; true uncertainties are somewhat greater.

<sup>b</sup>  $\gamma$  activity low because bias was  $\sim 0.33$  Mev instead of  $\sim 0.25$  Mev.

through the variety of chemical separations indicates that the residual activity is definitely aluminum, and that sample Al<sub>X</sub> was already essentially radiochemically pure.

Absorption measurements on Al<sub>X</sub> indicated  $\sim 1$ -Mev electrons; the weakness of the sample prevented an end-point determination. A low-resolution pulse analysis of the  $\gamma$ -activity present after the first 8-hydroxyquinoline precipitation ("Al<sub>W</sub>") showed peaks at 0.5 and 1.9 Mev, a band from 0.1 to 0.3 Mev, and a band from 0.8 to 1.6 Mev which seemed to contain some unresolved peaks. Broad-channel measurements of the smaller and weaker Al<sub>X</sub> showed the same distribution of pulses as in Al<sub>W</sub>, indicating that the Al<sub>W</sub>  $\gamma$  activity was essentially the same as that surviving the subsequent purifications. These observations are consistent with a dominant mode of disintegration of  $Al^{26g}$  by positron emission to the 1.83-Mev first excited state of  $Mg^{26}$ . The 0.5-Mev peak is presumably due to annihilation radiation, and the two bands principally to secondary effects. More definite characterization of the disintegration awaits the preparation of a more intense source.

The reactions responsible for  $Al^{26g}$  production are  $Mg^{25}(d,n)$  and  $Mg^{26}(d,2n)$ . In the absence of  $(d,n)$  and  $(d,2n)$  cross sections for comparable elements, we take the yield of each to be similar to that of  $Mg^{24}(d,\alpha)Na^{22}$  in the same cyclotron. The latter is 0.28 millicurie per 150  $\mu$ a-hr.<sup>11</sup> The specific  $\beta$  activity found indicates a total  $Al^{26g}$  activity of  $\sim 600$  disintegrations/minute in the 100 mg of Al carrier added to the target. Assuming

that equal amounts of  $Al^{26m}$  and  $Al^{26g}$  were produced and considering the relative abundances of the Mg isotopes, the above yield corresponds to a half-life of  $\sim 10^6$  years.

The occurrence of positrons in series with 1.83-Mev gammas eliminates the possibility<sup>1</sup> that  $Al^{26g} - Mg^{26g} = 2.5$  Mev. If, as follows from the most precise reaction data,<sup>5</sup>  $Al^{26g} - Mg^{26g} = 4.01 \pm 0.02$  Mev, the maximum positron energy is 1.16 Mev. The comparative lifetime is then  $\sim 10^{14}$  seconds, consistent with second-order forbiddenness, which would result if the  $Al^{26g}$  configuration is  $5+$  and that of the first excited  $Mg^{26}$  level is  $2+$  (rather than  $1+$  as favored by others<sup>12</sup>). The slowness of the transition eliminates the possibility<sup>9</sup> that the second excited state of  $Mg^{26}$  has a  $4+$  configuration.

Hitherto, aluminum has been the only element without either a radioactive or stable isotope suitable for tracing. If the problem of producing sufficient quantities of  $Al^{26}$  can be solved, this nuclide should be of considerable value in chemistry, metallurgy, and related fields.

\* This work has been supported by the U. S. Atomic Energy Commission. The cooperation of Professor Alexander J. Allen and the staff of the University of Pittsburgh Cyclotron Laboratory is gratefully acknowledged.

<sup>1</sup> Swann, Mandeville, and Whitehead, *Phys. Rev.* **79**, 598 (1950).

<sup>2</sup> Montalbetti, Katz, and Goldemberg, *Phys. Rev.* **91**, 659 (1953).

<sup>3</sup> Haslam, Roberts, and Robb, *Can. J. Phys.* **32**, 361 (1954).

<sup>4</sup> Kluyver, van der Leun, and Endt, *Phys. Rev.* **94**, 1795 (1954).

<sup>5</sup> C. P. Browne, *Phys. Rev.* **95**, 860 (1954).

<sup>6</sup> R. W. King and D. C. Peaslee, *Phys. Rev.* **90**, 1001 (1953).

<sup>7</sup> P. Stäbelin, *Helv. Phys. Acta* **26**, 691 (1953).

<sup>8</sup> P. Stäbelin, *Phys. Rev.* **92**, 1076 (1953).

<sup>9</sup> S. A. Moszkowski and D. C. Peaslee, *Phys. Rev.* **93**, 455 (1954).

<sup>10</sup> P. M. Endt and J. C. Kluyver, *Revs. Modern Phys.* **26**, 95 (1954).

<sup>11</sup> A. J. Allen (private communication from J. H. Gillette).

<sup>12</sup> J. E. May and B. P. Foster, *Phys. Rev.* **90**, 243 (1953).

## Orbital Electron Excitation Associated with Electron Capture in $A^{37}\dagger$

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(Received November 1, 1954)

RECENTLY, Miskel and Perlman<sup>1</sup> have analyzed in a proportional counter the pulse-height spectrum produced by the decay of  $A^{37}$ , which consists mainly of one peak, centered at 2.83 kev, the  $K$  binding energy of chlorine. They interpreted the processes giving rise to pulses in the region between 5.4 and 9.7 kev, after appropriately correcting the data, as  $K$ -electron excitation and ejection accompanying  $K$  capture. Theoretical computations on such processes had previously been carried out by Primakoff and Porter.<sup>2</sup> It is the purpose of this note to investigate the

magnitudes of two other processes which might give rise to a significant number of events in the energy interval considered. The two processes to be considered are  $L$ -electron excitation associated with  $K$ -electron capture and  $K$ -electron excitation accompanying  $L$  capture. Since the sum of the  $K$  and  $L$  binding energies corresponds to about 3.00 kev,<sup>3</sup> only excitation of electrons to unbound states in the above two processes can give rise to events in the energy region considered.

Primakoff and Porter<sup>2</sup> considered that  $K$  capture would give rise to no  $L$  excitation since they felt that the  $K$  electron exerts complete shielding on the  $L$  electrons before capture. In using the Slater<sup>4</sup> recipe for formulating atomic wave functions, one does however take only a shielding constant of 0.85 for the effect of a  $K$  electron on an  $L$  electron.<sup>5</sup> Using this number for the  $K$ -shielding constant, one finds for the total probability of  $2s$  and  $2p$  excitation  $0.27/Z_a^2$  compared to  $0.25/Z_b^2$  found by Primakoff and Porter for  $K$ -electron excitation,<sup>6</sup> where  $Z_b$  is the charge of the parent nucleus and  $Z_a$  is the charge of the parent nucleus minus 4.15 (the effective charge on an  $n=2$  electron shielded by two  $1s$  electrons and seven other  $n=2$  electrons). Only a fraction of these  $0.27/Z_a^2$  events would give rise to observations in the energy region looked at by Miskel and Perlman. The form of the energy distribution spectra for the  $2s$  and  $2p$  electrons was computed in the manner of Primakoff and Porter and gave rise to the corresponding expressions already computed for the case of beta decay by Levinger<sup>7</sup> multiplied by 0.0225 (this being the change in the effective value of  $Z$ ). One finds that processes in the energy region of interest occur with a probability of  $9 \times 10^{-6}$  per decay.

$K$ -electron excitation accompanying  $L$  capture gives rise to the same type of matrix elements as in the corresponding case of  $K$  capture except that now the change effective  $Z$  is more properly taken as 1. The  $L$ - to  $K$ -capture ratio is taken as 0.087.<sup>1</sup> Using this number, one finds for the probability of this process per  $K$  capture (remembering that there are two  $K$  electrons)  $0.174/Z^2$ .<sup>8</sup> Using the ejection probability spectrum, one finds that this process gives rise to events in the energy region of interest with a probability of  $5.1 \times 10^{-6}$  per decay.<sup>8</sup>

The total added probability we have calculated here is then  $6 \times 10^{-5}$  which compares with the theoretical value<sup>1</sup> of  $2.8 \times 10^{-4}$  expected for  $K$  excitation in  $K$  capture. The total theoretical probability is then  $3.4 \times 10^{-4}$  while the experiment of Miskel and Perlman gave a result of  $3.9 \times 10^{-4}$ . The added probability here calculated will also tend to bring the theoretical pulse-height distribution into better agreement with the experimental one although this has not been analyzed in detail. I am much indebted to Dr. J. Miskel and Dr. M. L. Perlman for stimulating discussions.

† Research carried out under the auspices of the U. S. Atomic Energy Commission.

<sup>1</sup> J. A. Miskel and M. L. Perlman, Phys. Rev. **94**, 1683 (1954).

<sup>2</sup> H. Primakoff and F. T. Porter, Phys. Rev. **89**, 930 (1953).

<sup>3</sup> We used 200 kev for the  $L$ -binding energy in chlorine although we should have used 200 and 280 kev for  $L_I$  and  $L_{II,III}$  binding energies respectively [B. Pontecorvo *et al.*, Phys. Rev. **75**, 982 (1949)]. This makes very little difference in the final results.

<sup>4</sup> J. C. Slater, Phys. Rev. **36**, 57 (1930).

<sup>5</sup> It must be admitted that this assertion has not been extensively tested.

<sup>6</sup> Both of these numbers need to be corrected due to the fact that other extra-nuclear electrons are present. Primakoff and Porter therefore add an extra multiplicative factor of uncertain magnitude. We shall discuss this correction in detail in a subsequent publication.

<sup>7</sup> J. S. Levinger, Phys. Rev. **90**, 11 (1953).

<sup>8</sup> This number would be correspondingly larger if the  $L$ -capture probability were found to be larger.

## Errata

**A New Titanium Nuclide:  $Ti^{44}$** , R. A. SHARP AND R. M. DIAMOND [Phys. Rev. **93**, 358 (1954)]. The value given for the half-life of  $Ti^{44}$ , 2.7 years, is too short. This value was obtained by a least-squares analysis of five months' decay data of a sample originally of an intensity of 122 counts/min in a Geiger counter. In this period, the sample decayed to 112 counts/min. Now, however, after fourteen months' total decay, the sample is still 112 counts/min. Apparently the original sample had about 10 counts/min of a shorter-lived contamination which decayed out and led to the erroneously short value given above. A lower limit to the true value can be obtained assuming that there has been decay to the extent of the possible counting errors. These correspond to about 2 percent decay in eight months or a half-life  $\geq 23$  years.

To prove that the activity remaining is indeed  $Ti^{44}$  scandium carrier was added to the sample and separated chemically as had been done in the original identification. The separated daughter activity was then counted with a scintillation counter by using a well-type NaI(Tl) crystal. The decay observed was the four-hour period of  $Sc^{44}$ , just as in the separations performed a year earlier on the same sample.

**Low-Energy Gamma Radiation from the Bombardment of Carbon by Protons**, H. H. WOODBURY, A. V. TOLLESTRUP, AND R. B. DAY [Phys. Rev. **93**, 1311 (1954)]. The value for  $\delta$  on page 1314, second column, should read " $\delta = 214 \pm 10^\circ$ " instead of " $\delta = 2.4 \pm 10^\circ$ ."

**The Angular Correlation of Three Nuclear Radiations**, G. R. SATCHLER [Phys. Rev. **94**, 1304 (1954)]. Delete  $i^{l'-l}$  from the first line of Eq. (4b) and insert it in the third line. Replace  $Y_{\nu}^{-m}$  in Eq. (5) by  $Y_{\lambda}^{-m}$ . In the first unnumbered equation of the right hand column of p. 1304, replace  $(-)^{J_1+J_2-1}$  by  $(-)^{J_1+J_2-L}$ .