

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.

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<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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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  $5.1 \times 10^{-5}$  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.

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<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.

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## Errata

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**A New Titanium Nuclide: Ti<sup>44</sup>**, R. A. SHARP AND R. M. DIAMOND [Phys. Rev. **93**, 358 (1954)]. The value given for the half-life of Ti<sup>44</sup>, 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<sup>44</sup> 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<sup>44</sup>, 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  $(-)^{J_1+J_2-L}$ .