alpha-activities and the isotopic compositions of the plutonium fractions of such samples.

The plutonium fractions of several samples subjected to different neutron fluxes were separated and carefully purified to spectrochemical freedom from foreign cations, to the absence of uranium (detected by a sensitive fluorescence test), and to radioactive purity. Duplicate portions of each plutonium fraction were converted to $PuF_3$ and reduced to high purity metal by microscale methods.[1]

Milligram globules of plutonium metal were massed against calibrated weights and dissolved in weighed quantities of solution. Aliquots were plated on platinum by a very precise gravimetric technique,[2] and counted on a parallel plate nitrogen counter ($N$-4) by methods previously described.[3] The isotopic compositions of the samples were available from the mass spectrometric examinations of Bartlett and Swinehart.[4] A minor change in the isotopic composition of sample $C$ indicated by a recent determination has been incorporated into the present calculation after correcting for the accumulated radioactive disintegration.[5]

Appropriate corrections for $Pu^{239}$ and the small amounts of $Pu^{238}$ and $Pu^{241}$ present were made in calculating the half-life of $Pu^{240}$ from the observed[3] specific activity of the samples relative to that of $Pu^{239}$.

The $Pu^{240}$ half-life calculated from three such plutonium fractions in order of increasing $Pu^{240}$ content were sample $A$, 6180±360 years; sample $B$, 6100±200 years; and sample $C$, 6310±130 years; with a best value of 6240±120 years. The indicated probable errors in these measurments includes consideration of the uncertainties in the mass spectrometry and weighing, limitation of spectrochemical sensitivity, observed standard deviations in the counting, and the probable error in the half-life of $Pu^{239}$.

It is noted that this half-life value is in accord with an estimate of about 6000 years by James *et al.*[6]

The general direction of Professor Glenn T. Seaborg and the cooperation of P. R. O'Conner and D. C. Stewart in the preparation of the samples and of A. Ghiorso in the counting procedures is gratefully acknowledged.

* Present address: Department of Chemistry, University of Michigan, Ann Arbor, Michigan.
† Formerly the Metallurgical Laboratory.
‡ Based on Manhattan Project Document CC-3894 (1946).
[1] E. F. Westrum, Jr., Manhattan Project Reports CK-1586 (1944), CN-2495 (1945). Reported in J. Am. Chem. Soc. **70**, 3543 (1948).
[2] E. F. Westrum, Jr., *The Transuranium Elements: Research Papers* (McGraw-Hill Book Company, Inc., New York, 1949), National Nuclear Energy Series, Vol. II, p. 1185.
[3] Westrum, Hindman, and Greenlee, *The Transuranium Elements: Research Papers* (McGraw-Hill Book Company, Inc., New York, 1949), National Nuclear Energy Series, Vol. II, p. 1717.
[4] A. A. Bartlett and O. F. Swinehart, Manhattan Project Document LA-561 (1946).
[5] M. G. Inghram and D. C. Hess (private communications).
[6] James, Florin, Hopkins, and Ghiorso, *The Transuranium Elements: Research Papers* (McGraw-Hill Book Company, Inc., New York, 1949), National Nuclear Energy Series, Vol. II, p. 1604.

## Half-Life of Plutonium-240 by Determination of Its Uranium-236 Daughter

M. G. INGHRAM, D. C. HESS, P. R. FIELDS, AND G. L. PYLE
*Argonne National Laboratory, Chicago, Illinois*
(Received July 27, 1951)

A NEW measurement of the $Pu^{240}$ half-life has been made using a technique which depends on the growth of the uranium daughters from a plutonium sample of known isotopic composition. The decays involved in this experiment are

$$Pu^{239} \xrightarrow[\alpha]{24{,}410\ \text{yr}^1} U^{235} \xrightarrow[\alpha]{7\times10^8\ \text{yr}}, \quad (1)$$

$$Pu^{240} \xrightarrow[\alpha]{\sim6000\ \text{yr}^2} U^{236} \xrightarrow[\alpha]{\sim2\times10^7\ \text{yr}^3}. \quad (2)$$

Since the time necessary to complete the experiment was short in comparison to the half-lives involved, the following simplified analytical expression can be obtained for the $Pu^{240}$ half-life:

$$T_{\frac{1}{2}}(Pu^{240}) = \frac{\text{moles of } U^{235}}{\text{moles of } U^{236}} \times \frac{\text{moles of } Pu^{240}}{\text{moles of } Pu^{239}} \times T_{\frac{1}{2}}(Pu^{239}).$$

The half-life thus obtained depends on the isotopic ratios of the uranium daughters and of the plutonium parents as determined by the mass spectrometer, and on the known half-life of $Pu^{239}$. Previous measurements of the $Pu^{240}$ half-life have been dependent on the $Pu^{239}$ half-life and on the ratio of the plutonium isotopes, but have also been subject to the errors inherent in specific activity measurements.

The plutonium used for this experiment was chosen because it contained a relatively large amount of $Pu^{240}$ and because it had been purified several years earlier with respect to the other heavy elements. After a chemical separation of the uranium daughters and subsequent purifications, an analysis on the alpha-differential pulse analyzer indicated that the final uranium fraction was sufficiently free of plutonium for mass spectrometric determinations.

The calculation of the half-life of $Pu^{240}$ involved two experimental errors: (1) The error in the half-life of $Pu^{239}$, which is given by Westrum as ±0.3 percent;[1] (2) the error in the mass spectrometric measurements of the isotopic ratios, which is about ±0.3 percent. It should be noted that the usual mass discriminations inherent in a mass spectrometer cancel in the present case. Substituting in the analytical expression, the values obtained on the mass spectrometer for the isotopic ratios of $Pu^{240}/Pu^{239}$ and $U^{235}/U^{236}$ and the value $T_{\frac{1}{2}}^{239}=24{,}410$ years,[1] gives the half-life of $Pu^{240}$ as 6580±40 years. This value and its limits of error is to be compared with those of 6240±120 yr,[4] 6850±150 yr,[5] and 6650±150 yr,[5] as determined by specific activity measurements.

The authors wish to express their appreciation to Dr. W. M. Manning for his helpful discussions of this problem.

[1] E. F. Westrum, Jr., *The Transuranium Elements: Research Papers*, (McGraw-Hill Book Company, Inc., New York, 1949), National Nuclear Energy Series, Division IV, **14B**, Paper No. 22.80.
[2] James, Florin, Hopkins, Ghiorso, *The Transuranium Elements: Research Papers*, (McGraw-Hill Book Company, Inc., New York, 1949), National Nuclear Energy Series, Division IV, **14B**, Paper No. 22.8.
[3] Ghiorso, Brittain, Manning, and Seaborg, Phys. Rev. **82**, 558 (1951).
[4] E. F. Westrum, Jr., Phys. Rev. **83**, 1249 (1951).
[5] Thompson, Street, Ghiorso, and Reynolds, to be published.

## Low Excited States of Nuclei and the Quasi-Atomic Model*

L. J. KOESTER,† H. L. JACKSON,‡ AND R. K. ADAIR
*University of Wisconsin, Madison, Wisconsin*
(Received July 23, 1951)

THE independent particle, or quasi-atomic model of the nucleus, has been used to discuss the ground states of nuclei[1,2] and the doublet splitting in light nuclei.[3] Recent experiments[4] on the elastic scattering of protons by $He^4$, $C^{12}$, $O^{16}$, and of neutrons by $He^4$ have been analyzed,[4,5] and assignments of angular momentum and parity have been made to the excited states observed. These quantum numbers have also been determined for some of the low states of $Al^{25}$ by an analysis of the scattering[6] of protons by $Mg^{24}$. Although these assignments are not all quite conclusive, we shall assume them to be correct for the purpose of discussion. The resulting series of energy levels, which are about 4 Mev in extent and lie near the ground states, show an interesting correlation with the predictions of an independent particle model with strong spin-orbit coupling.

One assumes that the nucleons of the target nucleus form a core of zero resultant angular momentum and that the influence of this core on the extra nucleon can be represented by an average potential. As a first approximation, this potential might be considered similar to that of a three-dimensional harmonic oscillator.