

Several radiogenic lead samples extracted from pitchblende have been analyzed. The results appear in Table I. Isotopic constitution of leads from Katanga and Great Bear Lake agree with determinations by Nier of samples from the same areas although the samples were obtained independently.

TABLE I. Isotopic analysis of several radiogenic lead samples.

1	2	3	4	5
Mineral and source	Pb ²⁰⁷ /Pb ²⁰⁶ (Toronto) %	Pb ²⁰⁷ /Pb ²⁰⁶ (Nier) %	Age (Toronto) millions of years	Age (Nier) millions of years
1. Pitchblende, Katanga, Belgium Congo	6.07 ± 0.06	6.00 to 6.13 (7 specimens)	640	610 to 655
2. Pitchblende, Port Radium, Great Bear Lake	8.82 ± 0.18	8.88	1400	1420
3. Pitchblende, Lake Athabaska	8.74 ± 0.17	—	1380	—

Note: In column 2 the errors given are mean deviations of observations.

Geological age calculations based on the formula in the first paragraph of this paper depend on the values of the half-lives of U²³⁵ and U²³⁸.

In 1939, Nier¹ chose a value of 7.07×10^8 years for the half-life of U²³⁵ in order to make age determinations based on the Pb²⁰⁷/Pb²⁰⁶ ratio agree with those obtained by the Pb²⁰⁶/U²³⁸ method. Some recent investigations^{2,4,5} give a higher value for the half-life of U²³⁵.

If a higher value than 7.07×10^8 years is adopted then all the ages in the geological time scale which are based on Nier's work must be increased; similarly, the estimates of the age of the earth calculated by Holmes' method⁶ will also be increased.

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† Holder of National Research Council of Canada Fellowship.

¹ A. O. Nier, Phys. Rev. **55**, 150 (1939).

² A. O. Nier, Phys. Rev. **60**, 112 (1941).

³ British Atomic Energy Report—BR-522 (1944).

⁴ Perlman, Ghiorso, and Seaborg, Phys. Rev. **77**, 26 (1950).

⁵ C. A. Kienberger, Phys. Rev. **76**, 1561 (1949).

⁶ A. Holmes, Nature **162**, 822 (1948).

The Specific Alpha-Activity of U²³⁵

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THE half-life of U²³⁵ has been the subject of several recent experimental investigations. Clark, Spencer-Palmer, and Woodward¹ reported a value of 8.91×10^8 years, derived from their alpha-pulse analyses of natural and enriched mixtures of U²³⁸, U²³⁵, and U²³⁴. Kienberger,² after remeasuring the specific activity and U²³⁴ content of normal uranium, computed the specific activity of U²³⁵ by subtraction and obtained a half-life of $(8.8 \pm 1.1) \times 10^8$ years. Knight³ obtained $(7.53 \pm 0.22) \times 10^8$ years for the half-life of U²³⁵ from specific activity measurements on highly enriched material and a crude pulse analysis for U²³⁴ and U²³⁵ alpha-particles. All of these values are substantially higher than Nier's^{4,5} recalculated⁶ figure of 7.07×10^8 years.

Because of the rather wide divergence among these various values, and also because of the general interest in the exact value of the U²³⁵ half-life, which enters into the computation of geological time, we have carried out several measurements of the specific alpha-activity of U²³⁵ in this laboratory.

The uranium used for this purpose was highly purified (99.9 percent) U²³⁵, supplied to us as U₃O₈ from Dr. C. E. Larson, Y-12

Plant, Carbide and Carbon Chemicals Division, Oak Ridge National Laboratory. Careful spectrographic analysis established that the chemical purity of this material was better than 99.95 percent.

Differential pulse analysis showed that (65.3 ± 0.7) percent of the alpha-activity was due to U²³⁵, and (34.7 ± 0.3) percent to U²³⁴. The details of this measurement are contained in another publication by Ghiorso.⁷

Samples of the oxide were weighed to ± 0.1 percent, and were then dissolved in concentrated nitric acid and diluted to volume. Accurate volume aliquots of these solutions were taken and the uranium electrodeposited quantitatively onto platinum disks. Thin, uniform films resulted of the order of 100–200 micrograms per sq cm. The highly enriched U²³⁵ depositions were counted in a specially constructed, helium filled, medium geometry counter [counting yield (8.313 ± 0.016) percent], which was calibrated with mixtures of U²³⁸ and U²³⁴ against a low geometry counter of accurately known counting yield. We believe that use of the medium geometry counter for the U²³⁵ samples reduced to negligible magnitude any errors arising from backscattering or self-absorption, since analysis of the pulses from this chamber showed an extremely flat plateau.

The specific activity of U²³⁵, as determined from five separate U²³⁵ depositions, was found to be 4774 ± 72 disintegrations per minute per milligram, with a corresponding decay constant of $(9.80 \pm 0.15) \times 10^{-10}$ per year, and a corresponding half-life of $(7.07 \pm 0.11) \times 10^8$ years.

Our value for the half-life agrees with the 7.07×10^8 year value reported by Nier.^{4,5,6} The value reported by Clark and co-workers, 8.91×10^8 years, differs from ours by about 25 percent. A partial explanation lies in the fact that these workers were unable to detect the high and low energy alpha-groups,⁷ comprising about 15 percent of the total disintegrations from U²³⁵, in their pulse analysis of slightly enriched U²³⁵ samples. However, it is difficult to account for the other 10 percent discrepancy.

The use of our value in the computation of the age of the earth as carried out by Holmes,⁸ reduces his figure of 3350 million years by about 3 percent.

A more precise value and a detailed description of this work are to be reported at a later date.

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³ G. B. Knight, Oak Ridge National Laboratory Report K-663 (1950) (unpublished).

⁴ A. O. Nier, Phys. Rev. **55**, 150 (1939).

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⁶ G. T. Seaborg and I. Perlman, Revs. Modern Phys. **20**, 585 (1948).

⁷ A. Ghiorso, Phys. Rev. **82**, 979 (1951).

⁸ A. Holmes, Nature **157**, 680 (1946).

Hyperfine Structure of Sm¹⁴⁹, Sm¹⁴⁷, Nd¹⁴⁶, and Nd¹⁴³

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THE hyperfine structure of the spectra of samarium and neodymium was studied, using the separated isotopes¹ of Sm¹⁴⁹, Sm¹⁴⁷, Nd¹⁴⁶, and Nd¹⁴³, respectively. The hollow-cathode light source² which was used contained about 25 milligrams of the sample. The cathode was made of aluminum and liquid-air or water cooling was used. The carrier gas was neon at a few mm Hg pressure. The fine structure was examined with a silvered Fabry-Pérot etalon and a Hilger constant deviation prism spectrograph. The maximum number of hyperfine components of any samarium line³ with a flag pattern was observed to be six, from which it follows that both Sm¹⁴⁹ and Sm¹⁴⁷ have spin 5/2.

The splitting of the ground term of Sm II for Sm¹⁴⁷ was determined from the structure of the line $\lambda 4704$ ($4f^6 6s^2 F_1 - 4f^6 6p 1^1_1$)

TABLE I. Nuclear spins and magnetic moments.

Isotope	Spin	Magnetic moment (nm)
Sm ¹⁴⁹	5/2	-0.25 ± 0.04
Sm ¹⁴⁷	5/2	-0.30 ± 0.05
Nd ¹⁴⁵	7/2	-0.62 ± 0.09
Nd ¹⁴³	7/2	-1.0 ± 0.2
$\mu(\text{Sm}^{147})/\mu(\text{Sm}^{149}) = 1.177 \pm 0.015$		
$\mu(\text{Nd}^{145})/\mu(\text{Nd}^{143}) = 1.60 \pm 0.06$		

and, neglecting the splitting of the initial term, that of the final term was found to be -0.120 cm^{-1} . Since the term $4f^6 6s^2 F_4$ can be regarded as due to a $4f^6 {}^7F_0$ configuration plus a $6s$ electron, we get the splitting factor $a(6s) = -0.040 \text{ cm}^{-1}$. Using the Fermi-Segrè-Goudsmit formula

$$\mu = a(s)In^* \times 118.5 / [ZZ^2 F dn^*/dn]$$

and putting $I = 5/2$, n^* (effective quantum number) = 2.18, $dn^*/dn = 1.08$, F (relativity correction factor) = 1.54, $Z = 62$, $Z_0 = 2$, we get the value of μ^{147} listed in Table I.

The Sm II line $\lambda 4515$ classified by us as due to a transition $J = \frac{1}{2} \rightarrow J' = \frac{1}{2}$ was observed to have three components 0 (26), 0.1149 (21), 0.1904 (26) cm^{-1} for Sm¹⁴⁷, where numbers in parentheses represent relative intensities. Similarly for Sm¹⁴⁹ the components 0 (26), 0.0974 (21), 0.1618 (26) cm^{-1} were obtained. Taking the ratio of the distances of the outermost components, μ^{147}/μ^{149} and hence the value of μ^{149} (since the value of μ^{147} is known) were obtained (see Table I).

In the case of Nd¹⁴³ or Nd¹⁴⁵, the line⁵ Nd II $\lambda 4303$ ($4f^4 6s {}^6I_{7/2} - 4f^4 6p {}^6K_{9/2}$) was observed to consist of at least six components, and the intensity distribution was in harmony only with the assumption of $I = 7/2$, neglecting the splitting of the initial term. The total splitting of the final term was found to be $+0.2604 \text{ cm}^{-1}$ and $+0.1623 \text{ cm}^{-1}$ for Nd¹⁴³ and Nd¹⁴⁵, respectively. The ratio μ^{143}/μ^{145} is listed in Table I. The spins of Nd¹⁴³ and Nd¹⁴⁵ and the ratio of the nuclear magnetic moments (μ^{143}/μ^{145}) given here are in good agreement with the recent work of Bleaney and Scovil.⁶

The usual formula⁷ for coupling of quantum vectors gives the relation for the splitting factor

$$A[4f^4({}^6I_4)6s {}^6I_{7/2}] = \frac{4}{63} \left[\frac{35}{2} a(4f^4 {}^6I_4) - \frac{7}{4} a(6s) \right],$$

which, when we neglect any contribution of the $4f$ electrons, yields $A = -\frac{1}{3}a(6s)$. Putting $a(6s) = 0.0837 \text{ cm}^{-1}$ for Nd¹⁴³ and $I = 7/2$, $Z = 60$, $Z_0 = 2$, $F = 1.491$, $n^*(6s) = 2.23$, $dn^*/dn = 1.08$ into the Fermi-Segrè-Goudsmit formula, we obtained the value of $\mu(\text{Nd}^{143})$, and hence that of $\mu(\text{Nd}^{145})$, listed in Table I.

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¹ Loaned by Union Carbide and Carbon Corporation, Oak Ridge.

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Gamma-Transitions in the Disintegration of Cerium 144

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CERIUM 144, with a half-life of ~ 300 days, was obtained from the Oak Ridge National Laboratory and aged for nine months to allow cerium 141 to decay. The sample was chemically separated from all other rare earth elements and other elements, the active isotopes of which may have been present. Cerium nitrate, without

TABLE I. Conversion electrons identified in praseodymium 144.

Electron energy in kev		Relative intensity	Gamma-ray energy in kev
38.2	K	medium	80.2 ± 0.5
73.5	L	weak	80.3
78.8	M	very weak	80
92.0	K	strong	134.0 ± 0.5
127.1	L	medium	133.9
132.5	M	weak	134

addition of carrier, was oxidized with permanganate and filtered with the manganese dioxide precipitated in acid solution. The manganese was reduced to divalent ion, and cerium was separated by adsorption of the latter on filter paper.

A sample of cerium 144 was prepared by evaporating the radioactive solution on a strip of zapon. A study of internal conversion electrons was made in a permanent magnet spectrograph set at 104 and 179 gauss, covering an energy range from 10 kev to 400 kev. Calibration of the instrument was obtained with the radiations of iodine 131.

Table I gives the energies and relative intensities of those internally converted electron groups for which identification of the corresponding gamma-ray energies has been established with certainty. Binding energies of the K, L, and M electrons of praseodymium and neodymium were considered in these cases. The agreement in energy values for the gamma-rays found were within 0.3-kev experimental error when the monoenergetic electron groups were attributed to transitions in praseodymium. On the contrary, when the binding energies of neodymium were used for calculation of the gamma-ray energies, discrepancies became as

TABLE II. Indirectly identified conversion electrons in praseodymium 144.

Electron energy in kev		Gamma-ray energy in kev
26.8	L	33.6
34.2	L	41.0
46.1	L	53.0
52.8	K	94.8
57.6	K	99.6
28.5	Auger	

large as 1.2 kev. Thus the energy difference between the conversion electrons corresponds more closely to the difference in binding energy in praseodymium, and the transitions are ascribed to this element.

Independently, the K and L conversion electrons of the 134-kev transition were observed with a beta-spectrometer and found to have an experimental K/L intensity ratio of about seven. The 134-kev transition is described in the literature as following the disintegration of Pr¹⁴⁴.

Other internal conversion electrons observed with the spectrograph are listed in Table II. Identification of these electron groups is less certain than those of Table I.

The electron groups of 26.8 kev and 34.2 kev are tentatively assigned to L conversion and the 52.8-kev and 57.6-kev groups to K conversion. The weakest electron line is that of 46.1 kev. If it is interpreted from experimental considerations as L conversion, then the gamma-rays of 53 kev would be due to a transition from the 134-kev level to 80 kev. This would account in part for the smaller experimental intensity of the 94.8-kev transition as compared to that of the 80.2-kev transition.

The energy balance for all observed levels in praseodymium up to 175 kev has been considered. One branch disintegrates by the consecutive transitions of 94.8 kev and 80.2 kev. The other branch disintegrates by the transitions of 41.0 kev, 99.6 kev, and 33.6 kev. The predominant transition, 134.0 kev, is a crossover of the 99.6-kev and the 33.6-kev transitions.

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