Internal conversion studies in ^{144}Nd†

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The relative electron intensities of eight transitions in ^{144}Nd were measured with a combination magnetic-Si(Li) spectrometer. The deduced internal conversion coefficients were compared with theoretical values in order to determine the multipolarity assignments for these transitions. With the assumption that the 618.0-keV transition is $E2$, the 476.8-, 582.4-, and 696.5-keV transitions were also found to be $E2$. The 301.7-, 778.6-, and 814.1-keV transitions were found to be predominantly $E1$. Our results are consistent with an $E0 + M1 + E2$ assignment for the 890.1-keV transition. The internal conversion studies confirm the spin and parity assignments for four excited states in ^{144}Nd which were previously proposed mainly on the basis of angular correlation measurements.

[RADIOACTIVITY ^{144}Pm [from ^{145}Nd$(p, 2n)$]; measured I_{ce}. Deduced ICC. ^{144}Nd deduced levels, J, π, γ mixing. Magnetic-Si(Li) spectrometer.]

I. INTRODUCTION

The electron-capture decay of ^{144}Pm populates[1] six excited states in ^{144}Nd. Nine γ transitions with intensities >0.03 per 100 decays of ^{144}Pm are known to deexcite these levels as shown in Fig. 1. Recently, Behar, Grabowski, and Raman[2] have carried out $\gamma\gamma$ angular correlation measurements in order to establish spin assignments for these excited states. Their assignments, included in Fig. 1, differ from those given earlier by Arya, Turk, and Arya,[3] also from angular correlation measurements. Furthermore, the parity assignments in Ref. 2 were based on a variety of results including earlier conversion electron measurements[4,5] limited to the strong 477-, 618-, and 696-keV transitions, the presence of a primary γ ray to the 1511-keV level in (n,γ) reactions, and the γ-decay pattern of the 2093-keV level. In the present paper, we describe more detailed internal conversion measurements carried out with a ^{144}Pm source which confirm the spin and parity assignments shown in Fig. 1 in a more direct fashion.

II. EXPERIMENTAL PROCEDURES AND RESULTS

The internal conversion measurements were made with ^{144}Pm sources produced by the ^{145}Nd$(p, 2n)$ reaction and subsequent ion-exchange separation. Thin sources were prepared through electrodeposition. The measuring instrument was a specially designed and constructed spectrometer[6] capable of measuring the intensities of weak conversion lines. The spectrometer was of a combination magnetic-Si(Li) type, operating upon the principle that the magnetic lens system can be made to select a broad region of electron momentum spectrum for simultaneous energy analysis by a high-resolution Si(Li) detector.

The momentum acceptance corresponds to an energy band of about 100 keV. The energy resolution of the instrument then is entirely dependent on the quality of the Si(Li) detector and the associated electronics. The intensity of each electron line, measured in either the swept-current or fixed-current mode, is taken to be the number of counts under the full energy peak of the silicon detector spectrum. A small correction must be applied to account for the variation in momentum acceptance with current and also for the variation in the detection efficiency with electron energy caused by electrons which scatter out of the detector without depositing all of their energy. The two variations are found to partially cancel each other, and the small correction factors applied were measured with a set of calibration sources (^{106}Ru + ^{106}Rh, ^{133}Ba, ^{154}Eu, and ^{207}Bi) having conversion-electron lines of well-known intensities.

The intensities of the strong conversion lines of the 476.8-, 618.0-, and 696.5-keV transitions were first measured by sweeping the current linearly in time and recording the spectrum of the high resolution Si(Li) detector with a multichannel analyzer. The intensities of all the lines were then measured by fixing the current at values corresponding to the maximum transmission for the particular electron

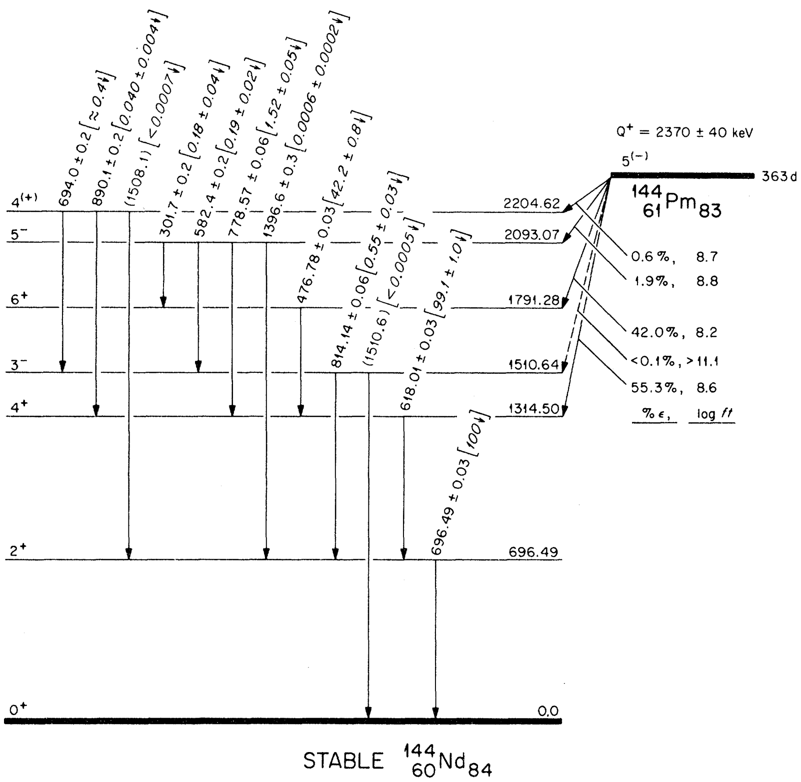

FIG. 1. Decay scheme of ^{144}Pm proposed in Refs. 1 and 2. All energies are in keV. The italic numbers next to the γ-ray energies refer to transition intensities per 100 decays of ^{144}Pm.

energy of interest. The fixed-current technique is particularly useful in cases where the electron intensity is very small. The swept-current spectrum is shown in Fig. 2, while samples of the conversion data recorded with the magnet current fixed are shown in Fig. 3. The large variation in the line widths (see Fig. 3) is simply a result of adjusting the gain and bias of the amplifier associated with the Si(Li) detector and has no physical

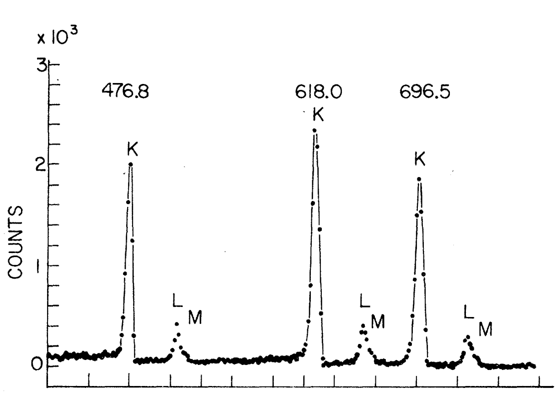

FIG. 2. Spectrum showing the strong internal conversion lines in ^{144}Nd recorded with the swept-current mode of the magnetic-Si(Li) spectrometer.

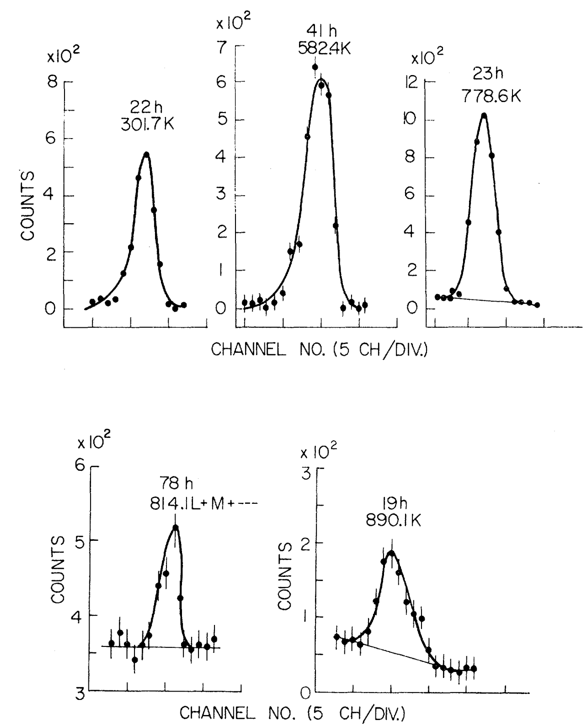

FIG. 3. The weak internal conversion lines in ^{144}Nd recorded with the fixed-current mode of the magnetic-Si(Li) spectrometer. The time expended in obtaining the data is also shown for each peak.

TABLE I. Measured conversion electron intensities in ^{144}Nd.

E_γ (keV) [a]	Rel. I_γ [a,b]	Rel. I_{ce} [c]	Shell
301.7 ± 0.2	1.8 ± 0.4	4.15 ± 0.42	K
476.78 ± 0.03	418 ± 7	824 ± 33	K
582.4 ± 0.2	1.9 ± 0.2	2.44 ± 0.24	K
618.01 ± 0.03	984 ± 10	1000	K
694.0 ± 0.2	≈4 }	768 ± 38	K
696.49 ± 0.03	1000 }		
778.57 ± 0.06	15.2 ± 0.5	5.3 ± 0.3	K
814.14 ± 0.06	5.5 ± 0.3	0.20 ± 0.04	$L+M+\cdots$
890.1 ± 0.2	0.40 [d] ± 0.04	1.20 ± 0.12	K

[a] Previous results from Refs. 1 and 2.
[b] Relative photon intensity normalized to 1000 for the 696.49-keV transition.
[c] Relative conversion electron intensity normalized to 1000 for the K—618.01-keV transition.
[d] New value compared to the old value of 0.40 ± 0.10.

significance. The weak lines were run several times in order to check the consistency of the data. The 301.7- and 582.4-keV lines shown in Fig. 3 have been stripped off a smooth continuous background due to the scattered electrons from the very strong transitions at higher energies. The other lines are as they appeared in the analyzer memory. In the case of the 814.1-keV transition, the K peak could not be resolved well enough from the nearby L peak of the 778.6-keV transition. Therefore, we measured the $L+M+\cdots$ intensity of the 814.1-keV transition which is sufficient, in this case, to establish its multipolarity.

The measured relative internal conversion electron intensities are given in Table I along with previously measured[1] relative photon intensities. The deduced conversion coefficients are given in Table II. While the 696.5-keV transition is known to be $E2$ from Coulomb excitation, the 618.0-keV transition rather than the 696.5-keV transition was employed for normalization because we did not resolve the weak 694.0-keV transition from the strong 696.5-keV transition. The 618.0-keV transition is also pure $E2$. The theoretical values of the conversion coefficients given in Table II were obtained through interpolation from the tables of Hager and Seltzer.[7]

III. DISCUSSION

A detailed level-by-level discussion of the spin and parity assignments for levels in ^{144}Nd has been already provided in Ref. 2 and, therefore, will not be repeated here. Concerning the spin assignment for the 1791.3-keV level, we wish to stress that angular correlation measurements alone cannot distinguish between $J=4$ and $J=6$, because both the $6 \to 4 \to 2$ and $4 \to 4 \to 2$ [if $\delta(476.8\gamma)=0.26$] sequences have the same A_2, A_4 values. However, as soon as it is established that the 476.8-keV transition is $E2$ (see Table II), the angular correlation results rule out $J=4$ and a definite 6^+ assignment can be made for the 1791.3-keV level.

Another question which can be settled by the present internal conversion measurements is that of the J^π assignment for the 1510.6-keV level. The measured $\alpha_{L+M+\cdots}$ value for the 814.1-keV transition implies that this transition is predominantly $E1$, which is consistent with the 3^- assignment proposed in Ref. 2 but not with the 2^+ assignment of Ref. 3.

The measured $\alpha_K(301.7\gamma)$ and $\alpha_K(582.4\gamma)$ values imply that the 301.7-keV transition is predominantly $E1$ and that the 582.4-keV transition is $E2$. The

TABLE II. Internal conversion coefficients for γ transitions in ^{144}Nd.

E_γ	Quantity [a]	Experimental value (in units of 10^{-3})	Theoretical value [b] (in units of 10^{-3}) $E1$	$M1$	$E2$	$M2$	Deduced multipolarity
301.7	α_K	12.9 ± 2.5	11.5	58.3	40.9	240	$E1+<2\%M2$
476.8	α_K	11.0 ± 0.5	3.77	17.9	11.1	57.9	$E2$
582.4	α_K	7.2 ± 1.1	2.40	10.9	6.59	32.2	$E2$
618.0	α_K	5.69 [c]			5.69		Assumed $E2$
696.5	α_K	4.30 ± 0.24 [d]			4.27		Known $E2$
778.6	α_K	1.95 ± 0.13	1.31	5.34	3.30	14.2	$E1+(5\pm1)\%M2$
814.1	$\alpha_{L+M+\cdots}$	0.20 ± 0.05	0.20 [e]	0.84 [e]	0.57 [e]	2.37 [e]	$E1+<3\%M2$
890.1	I_{ce_K}/I_γ	16.8 ± 2.4	1.01 [f]	3.88 [f]	2.44 [f]	9.86 [f]	$E0+M1+E2$

[a] Internal conversion coefficient α defined as I_{ce}/I_γ.
[b] From Ref. 7.
[c] Assumed value for normalization.
[d] Uncertainty increased from 0.22 to 0.24 to reflect the fact that the 694.0-keV transition was ignored.
[e] Theoretical $1.33\alpha_L$ values.
[f] Theoretical α_K values.

$\alpha_K(778.6\gamma)$ value is consistent with a multipolarity assignment of $E1+(5\pm1)\%\ M2$ which is in reasonable agreement with a dipole-quadrupole admixture of $D+(2.1\pm0.3)\%\ Q$ from angular correlation results. The multipolarity assignments for the 301.7-, 582.4-, and 778.6-keV transitions definitely establish $J^\pi=5^-$ for the 2093.1-keV level.

The $\alpha_K(890.1\gamma)$ value was measured several times and found to be larger than that expected for $E1$, $M1$, $E2$, or $M2$ multipolarities or any mixture of these. The spin of the 2204.6-keV level has been previously shown to be $J=4$ from angular correlation studies.[2] We conclude that the 890.1-keV transition which deexcites the 2204.6-keV level to the 1314.5-keV, 4^+ state is most probably an $E0+M1+E2$ transition. The 2204.6-keV level would then have positive parity. If we assume that the 890.1-keV transition is $E0+M1$, we would obtain $\Gamma_K(E0)/\Gamma_K(M1)=3.3\pm0.6$, where Γ is the absolute decay probability. With the $E0+E2$ assumption, $\Gamma_K(E0)/\Gamma_K(E2)=5.8\pm1.0$. We cannot directly evaluate the monopole strength of the transition because the lifetime of the 2204.6-keV level is not known. Such a measurement would be of considerable interest.

In summary, we have determined the multipolarities of seven transitions in ^{144}Nd by studying their internal conversion electrons. We have confirmed the spin and parity assignments for four states in ^{144}Nd populated in the decay of ^{144}Pm.

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