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Several investigations of the beta decay of Nd^{147} to the excited states of Pm^{147} have all been characterized by the failure to observe any direct beta transition to the ground state.[1] The most intense beta line is a first-forbidden transition to the first excited state, which then decays to the ground state by an M1 gamma-ray transition. These observations are very difficult to explain, in view of a recent measurement, by paramagnetic resonance, of 5/2 for the ground-state spin of Nd^{147},[2] and the probable assignment of the ground-state of Pm^{147} on the basis of the single-particle shell model.[3] In the hope of improving our knowledge concerning this situation, we have undertaken to measure by the method of atomic beams, the spins of these isobars. Our results confirm the paramagnetic resonance measurement of $I = 5/2$ for Nd^{147} and yield $I = 7/2$ for Pm^{147}.

Prior atomic-beam measurements on stable neodymium have established the existence of a low-lying electronic state characterized by $J = 4$ and $g_J = 0.6$ Such an electronic state is coupled by the hyperfine-structure interaction to a nuclear spin of $I = 5/2$ to result in six nondegenerate levels of the total angular momentum (F) with Landé splitting factors given by

$$g_F \approx 0.603 \frac{F(F+1) + 55/4}{2F(F+1)} , \qquad (1)$$

where a term in the nuclear moment has been neglected.

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In an atomic-beam apparatus with flop-in magnet geometry and normal ordering of the F states, transitions in the highest four F states are observable. We have observed transitions in the $F = 13/2$, $11/2$, and $9/2$ states at two magnetic fields. The g_F values corresponding to the observed resonant frequencies are given in Table I along with the values predicted from Eq. (1). The discrepancies between the calculated and experimental g_F values are probably due to quadratic shift resulting from a small hyperfine structure. The failure to observe the transition in the $F = 7/2$ state is probably due to the inability of the apparatus to refocus transitions for which $\Delta m_J = \pm 1$ for such low g_J values.

The Nd^{147} used in these runs was produced by neutron irradiation of commercially obtained material which was spectroscopically verified to be > 99% neodymium by weight. The method of production, together with the 11.5-day half-life established for the decay of a foil exposed to the neodymium beam at resonance and the g_J value, uniquely determines the material to be Nd^{147}.

The Pm^{147} used in these experiments was obtained in a weak HCl solution from Oak Ridge National Laboratory, and is guaranteed by the supplier to be > 99% pure. It is found that a satisfactory procedure for obtaining a beam of atomic promethium is to convert the material to the nitrate and mix the nitrate salt with an excess of lanthanum metal in the atomic-beam oven. The oven is then heated slowly up to operating temperature (about 1000°C), at which temperature a beam of atomic promethium is formed. The mechanism for the reaction is believed to be the initial decomposition (at low temperatures) of promethium nitrate to promethium oxide, then the reduction by the lanthanum (at some higher temperature) to the metal.

Since no prior information concerning the electronic ground state of promethium existed, a systematic search was initiated at low magnetic fields to observe resonances within the range of g values $0 \leq g \leq 2.0$. Three resonances were observed, each of which was followed up in field to a maximum field of 38.2 gauss. Table II gives the g_F values corresponding to the observed resonant frequencies.

Interpretation of these data is based on the assumption that the ground-state configuration of promethium is $(4f)^5$. This hypothesis is supported by the fact that the ground-state configuration of $_{60}$Nd and $_{62}$Sm are known to be $(4f)^4$ and $(4f)^6$,[5,6] respectively. A calculation of the electrostatic energies indicates that the Hund's Rule term ^6H is expected to be the ground state. The spin-orbit interaction will split this term into six J states, with the $J = 5/2$ state lying lowest. An estimate of the separations can be obtained from the fine-structure splitting constant, measured in the optical spectrum of samarium to be about $a_{4f} \approx 1100\ \text{cm}^{-1}$.[6] This indicates that the $J = 5/2$, 7/2, and 9/2 states should all be present in measureable amounts in the beam. The $J = 7/2$ and $J = 9/2$ states are easily refocussed, and the L-S coupled g_J values are given in Table II and compared with the values inferred from the experimental data on the assumption $I = 7/2$. The state $J = 5/2$ is not observed, for the g_J value of atoms in this state is too low to allow refocussing in our apparatus.

In analogy with the other rare earth elements, the only possible ground state configuration besides $(4f)^5$ could be $(4f)^4\,(5d)$. An attempt to exclude the possibility of a data fit for the configuration $(4f)^4\,(5d)$ can be made on the following basis. Judd has calculated the electrostatic energies for f^4d and has shown that for this configuration the Hund's Rule term should lie lowest.[7]

This term will give rise to states with all half-integral J values from $J = 11/2$ through $J = 21/2$, of which several would be present in the beam. An attempt has been made to fit the observed data in a g_J-independent way, i.e., by trying to fit ratios of the observed frequencies to ratios of the cosine factors $\frac{F(F+1)+J(J+1)-I(I+1)}{2F(F+1)}$ that arise from all possible F's corresponding to a given I and J. All values of I from 3/2 to 13/2 and all values of J from 3/2 to 21/2 were tried. No fit was obtained to all of the data for a single I and J. We are also able to exclude the case of two resonances occuring in one electronic state state, and the third resonance occuring in another, except for the assigned I and J's. Hence we conclude that the spin of Pm^{147} is 7/2, that $(4f)^5$ is the ground-state configuration, and that L-S coupling to the Hund's Rule ground state gives an excellent approximation to the observed g values. It is of interest to note that the ground-state configuration of neptunium, the actinide homologue of promethium, is $(5f)^4 (6d)^1$.[8]

The most plausible shell-model interpretation of the observed spin of Pm^{147} is to assign the 61st proton to the level 1g 7/2. This implies that the 2d 5/2 level lies lower than the 1g 7/2 level. The measured spins of $_{59}Pr^{14}$ and $_{63}Eu^{151,153}$ are all 5/2,[9, 10] which indicates that for these nuclei the converse is true. The configuration $(d5/2)^3$ coupling to $J = 7/2$ is forbidden by the Pauli principle.

The measured spins of the ground states of Nd^{147} and Pm^{147}, taken along with the beta decay information, indicate that the spin of the first excited state of Pm^{147} is either 5/2 or 7/2. It is difficult to understand the failure to observe the direct beta decay between the ground states of Nd^{147} and Pm^{147} on the basis of the now known spins, and the ordinary selection rules governing beta decay. It is possible that in this particular case some unusual effect results in a modification of the selection rules.

Table I

Observed resonances in Nd^{147}. The calculated g_F's are based on the previously measured g_J's[4]

μ_0 H/h (Mc)	Transition		
	I = 5/2, J = 4 F = 13/2	I = 5/2, J = 4 F = 11/2	I = 5/2, J = 4 F = 9/2
5.880	0.371 ±0.018	0.394±0.020	0.438±0.021
9.679	0.3755±0.0021	0.4008±0.0026	0.4452±0.0025
mean experimental g_F	0.3755±0.0021	0.4008±0.0026	0.4452±0.0025
calculated g_F	0.3710	0.3943	0.4385

Table II

Observed resonances in Pm^{147}. The calculated g_F's are based on the assumption of pure L-S coupling among the electrons of the configuration f^5 to the Hund's Rule term ^6H

μ_0 H/h (Mc)	Transition		
	I = 7/2, J = 7/2 All F	I = 7/2, J = 9/2 F = 8	I = 7/2, J = 9/2 F = 7
15.208	0.416±0.002	0.600±0.003	0.620±0.003
29.050		0.602±0.002	0.623±0.002
53.528	0.4164±0.0010	0.6044±0.0015	0.6230±0.0015
mean experimental g_F	0.4164±0.0010	0.6037±0.0015	0.6230±0.0015
calculated g_F	0.4127	0.6023	0.6214

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