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"Missing" $\frac{19}{2}^+$ states in ^{141}Pr and ^{143}Pm

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A simple weak coupling model previously applied to the analysis of the yrast spectrum of ^{143}Nd is extended to yrast spectra of odd-A $N=82$ and 83 isotopes of $Z=58-61$ nuclei. The model generally provides a good description of these spectra; however, yrast $\frac{19}{2}^+$ states expected to arise in ^{141}Pr and ^{143}Pm from the coupling of $\pi g_{7/2}$ holes to the 6_1^+ states of the even-even cores are not observed experimentally. The absence of these states can be explained using a simple microscopic argument.

A recent experimental study[1] of high angular momentum states of the $N=83$ nucleus ^{143}Nd concluded that its yrast spectrum could be explained with the use of a zero-order weak coupling model.[2] In such a model, the energy of a state of an odd-A nucleus is calculated to be the sum of the energy of the corresponding state of the even-even core nucleus and the single particle energy of the correct odd nucleon orbit. This success was not unexpected. The same approach has been used to understand the nuclei[3] which are one nucleon removed from the spherical nucleus ^{146}Gd. Furthermore, Ring and Schuck[4] concluded from empirical evidence that a weak coupling model is generally sufficient to describe spectra of odd-A nuclei for which the deformation parameter β_2 of the even-even core obeys the relation

$$\beta_2 A^{2/3} < 4 \ . \tag{1}$$

For $A=150$, this relation requires $\beta_2 < 0.14$. A recent compilation[5] shows that β_2 values in the even-A $N=82$ isotones for which they are known (Ce, Nd, Sm) are 0.10 or less, satisfying the weak coupling condition of Eq. (1). Therefore, it would be expected that weak coupling would provide a reasonable description of the yrast spectra of nuclei adjacent to the even-A $N=82$ nuclei, including the $N=83$ and $N=82$ odd-A nuclei.

The model under discussion is quite simple. Nevertheless, we demonstrate here that it is useful for identifying anomalies in spectra of odd-A nuclei. We extend the zero-order weak coupling analysis to high angular momentum spectra of the $N=82$ nuclei[6,7] ^{141}Pr and ^{143}Pm and the $N=83$ nucleus[8] ^{141}Ce and show that it generally explains the features observed. However, the weak coupling analysis predicts that yrast $\frac{19}{2}^+$ states should be present in both ^{141}Pr and ^{143}Pm. These states are not observed in either nucleus experimentally. This anomaly is explained in the present work with an argument based on the microscopic structure of the $\frac{19}{2}^+$ states, demonstrating a limitation of the weak coupling approach.

The single-particle orbits in the region under discussion are $2f_{7/2}, 1h_{9/2}$, and $1i_{13/2}$ for neutrons and $1h_{11/2}$ for protons. For the $N=83$ nuclei ^{141}Ce and ^{143}Nd, the lowest available orbit for the odd neutron is $f_{7/2}$; we might also expect to observe $h_{9/2}$ and $i_{13/2}$ neutrons in the near-yrast spectra as well. The single neutron energies for these orbits are taken from the dominant single-particle states observed[9,10] in (d,p) experiments and are tabulated in Table I. If the $N=82$ isotopes ^{140}Ce (Ref. 11) and ^{142}Nd (Ref. 12) are taken to be the core nuclei, then the results of the weak coupling calculations are those shown in Fig. 1. The parities of a number of states in both ^{141}Ce and ^{143}Nd are unknown; however, the correspondence between these states and calculated weak coupling energies is good, suggesting both configurations and parities for these states.

In the weak coupling framework, we would expect states in ^{141}Pr and ^{143}Pm to arise from the coupling of $d_{5/2}$ and $h_{11/2}$ protons and $g_{7/2}$ proton *holes* to even-even core nuclei. For ^{141}Pr, the core nucleus would be ^{140}Ce for $d_{5/2}$ and $h_{11/2}$ particle states, and ^{142}Nd for $g_{7/2}$ hole states. In ^{143}Pm, particle states would have a ^{142}Nd core and the hole states would have a ^{144}Sm core.[13] The single-particle energies for $d_{5/2}$ and $h_{11/2}$ protons are from the dominant single-particle states in $(^3\mathrm{He},d)$ studies[14,15] and are listed in Table II; $g_{7/2}$ hole states are located with $(d,^3\mathrm{He})$ data[16,17] and are also listed in Table II. The weak coupling calculation results for ^{141}Pr and ^{143}Pm are compared with high-spin data in Fig. 2. Once again, states arising in the weak coupling scheme generally correspond well with the observed states. However, the $\frac{19}{2}^+$ states which would be expected to arise in both ^{141}Pr and ^{143}Pm from the coupling of the 6_1^+ states of the core nuclei to the $g_{7/2}$ hole are not observed experimentally, even though they would be yrast in both nuclei. A $\frac{19}{2}^+$ state is observed near 3.0 MeV in ^{141}Pr, but it is far above the 2.3-MeV energy calculated in the weak coupling scheme. Clearly, the weak coupling model is inadequate for explaining this behavior.

An explanation for these "missing" $\frac{19}{2}^+$ states can be formulated using a simple microscopic picture of the core 6^+ state. In ^{142}Nd, which is the core for the $g_{7/2}$ hole states in ^{141}Pr, the 6_1^+ states can arise from either $g_{7/2}^7 d_{5/2}^3$ or $g_{7/2}^6 d_{5/2}^4$ configurations. For the $g_{7/2}^7 d_{5/2}^3$ case, the angular momentum is generated by the coupling of the odd $d_{5/2}$ proton to the odd $g_{7/2}$ proton. In the $g_{7/2}^6 d_{5/2}^4$ case, the spin would result from the coupling of two unpaired $g_{7/2}$ protons. If a paired $g_{7/2}$ proton is removed from the $g_{7/2}^7 d_{5/2}^3$ configuration, then the max-

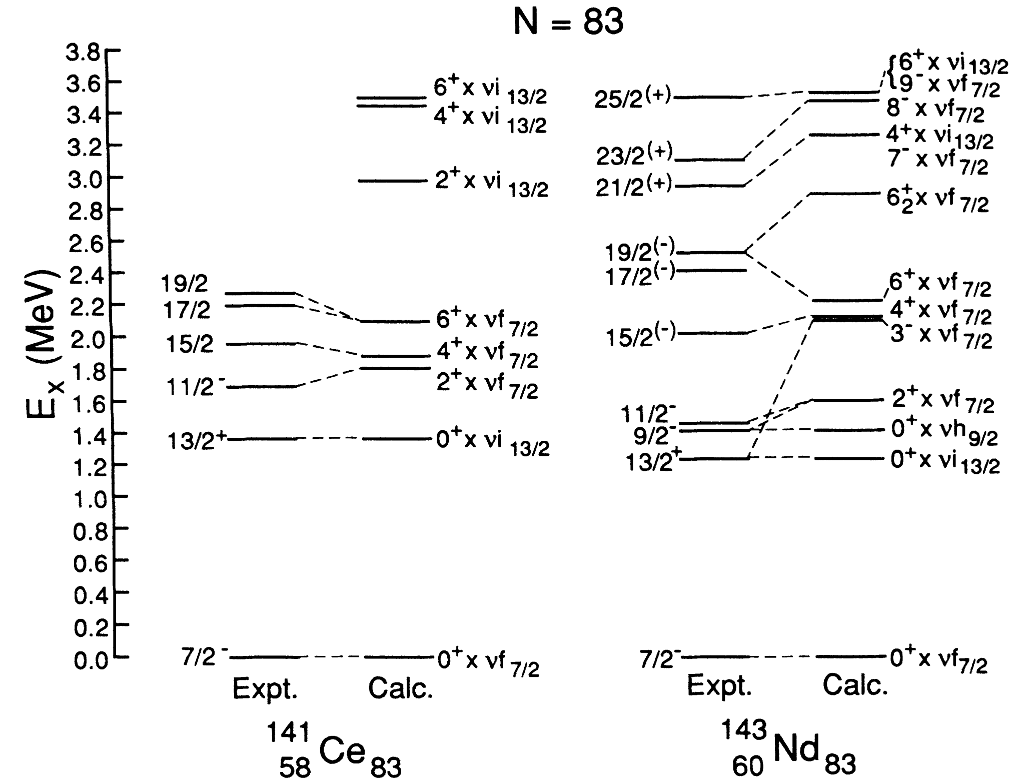

FIG. 1. Comparison of experimentally observed levels in the $N=83$ isotopes, Ce and Nd, with those calculated by zero-order weak coupling calculations. The configurations are given in terms of ^{140}Ce(J) [and ^{142}Nd(J)] and single-particle states given in Table I.

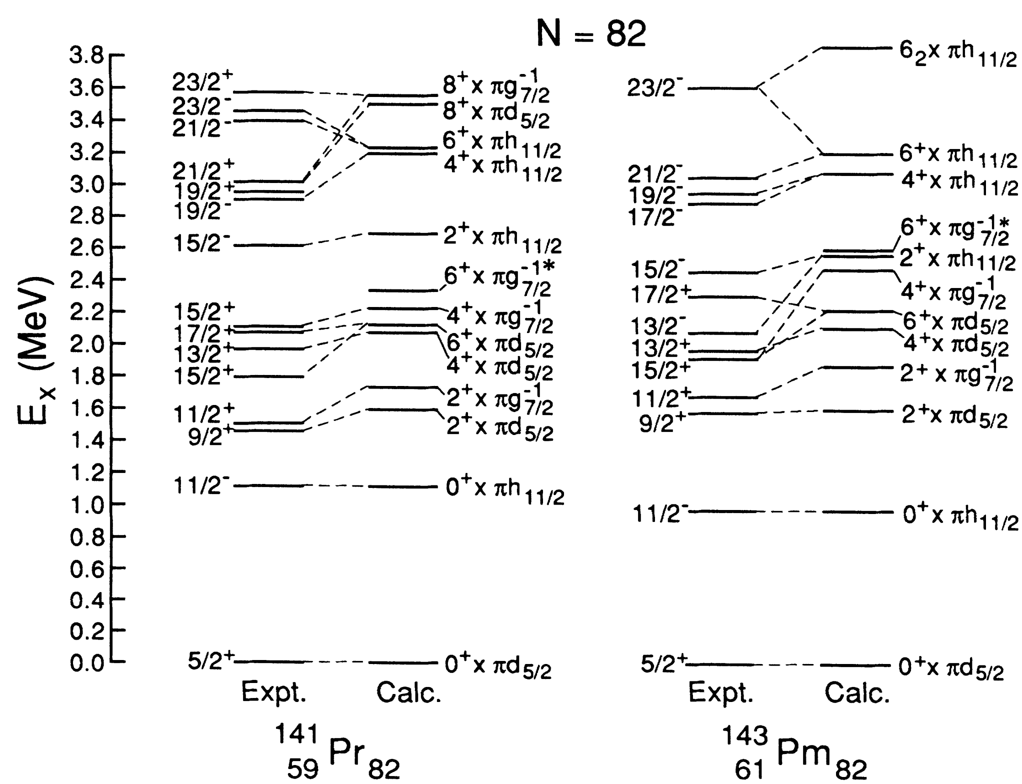

FIG. 2. Same as in Fig. 1. The "missing" $\frac{19}{2}^+$ positions are labeled with stars.

TABLE I. Energies and spectroscopic factors for the $N=83$ single-particle states obtained from the (d,p) reactions.

	^{141}Ce$^{(a)}$ Expt.	S'	^{143}Nd$^{(b)}$ Expt.	S'
$f_{7/2}$	0.00	0.79	0.00	0.75
$h_{9/2}$	1.36	0.70	1.41	0.58
$i_{13/2}$	1.37	0.64	1.23	0.45

[a]Reference 9.
[b]Reference 10.

TABLE II. Energies and spectroscopic factors for the $N=82$ single-particle and hole states obtained from the (^{3}He,d) and (d,^{3}He) reactions.

	^{141}Pr$^{(a)(b)}$ Expt.	S'	^{143}Pm$^{(c)(d)}$ Expt.	S'
$d_{5/2}$	0.00	1.00	0.00	0.50$^{(e)}$
		0.42		0.53$^{(f)}$
$g_{7/2}$	0.14	0.35	0.27	0.13$^{(e)}$
		0.79		0.94$^{(f)}$
$h_{11/2}$	1.11	1.31	0.96	0.93$^{(e)}$
		0.06		0.12$^{(f)}$

[a]Reference 14.
[b]Reference 16.
[c]Reference 15.
[d]Reference 17.
[e]Observed by the (^{3}He,d) reactions.
[f]Observed by the (d,^{3}He) reactions.

imum angular momentum $\frac{17}{2}h$ is generated if the two unpaired $g_{7/2}$ protons and one unpaired $d_{5/2}$ proton couple to their maximum angular momentum. If a paired $g_{7/2}$ proton is removed from the $g^6_{7/2}d^4_{5/2}$ configuration, then three unpaired $g_{7/2}$ protons can couple to a maximum angular momentum of $\frac{15}{2}h$. An assumption implicit in the weak coupling approach is that the state of the odd-A nucleus possesses the same number of broken pairs as the corresponding state in the core nucleus. We conclude that there is no way of coupling to a spin of $\frac{19}{2}h$ without breaking additional nucleon pairs and violating this assumption of the weak coupling approach. A similar explanation accounts for the "missing" $\frac{19}{2}^+$ state in ^{143}Pm.

In conclusion, we find that the zero-order weak coupling model previously applied to ^{143}Nd is adequate for describing the high angular momentum spectra of ^{141}Ce, ^{141}Pr, and ^{143}Pm. However, when the angular momentum of a state requires the odd particle or hole to alter the microscopic structure of the core excitation, as in the cases of the missing $\frac{19}{2}^+$ states of ^{141}Pr and ^{143}Pm, the weak coupling model breaks down.

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