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Short note

Study of high-spin states in ^{143}Pm

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Abstract. High-spin states in ^{143}Pm have been investigated via the ^{128}Te(^{19}F,4nγ)^{143}Pm reaction using techniques of in-beam γ-spectroscopy. γ-ray singles, γ-γ coincidences, γ-ray anisotropies and DCO ratios have been measured. Based on these measurements, the level scheme of ^{143}Pm has been extended up to an excitation energy of 10535.4 keV, including 48 new γ-rays deexciting 28 new levels. The yrast levels in ^{143}Pm can be understood qualitatively in the framework of a weak-coupling model.

PACS. 23.20.Lv Gamma transitions and level energies – 27.60.+j $90 \leq A \leq 149$

The weak-coupling model [1] is a useful tool to interpret nuclear structure data owing to its ease of application and utility in comparison among a number of nuclei. One common application of the weak-coupling model is the interpretation of the yrast levels in odd-A nuclei, arising from the coupling of the valence nucleon to states in the corresponding even-even core. Many odd-A nuclei near $Z = 64$, $N = 82$ exhibit a level structure with spin sequences and energy spacings similar to those of the yrast levels of adjacent even-even nuclei. This indicates that the valence nucleon does not interfere with the core excitations and the coupling between the odd nucleon and the core may be weak. The ^{143}Pm can be regarded as a proton particle plus a ^{142}Nd core or a proton hole plus a ^{144}Sm core, thus the high-spin data in ^{143}Pm may provide a pertinent background to test the applicability of weak-coupling approach in this mass region.

Prior to this work, the level scheme of ^{143}Pm was established experimentally up to $J^\pi = (25/2^+)$, $E_x = 4580.1$ keV [2,3], and the level structure has been discussed on the basis of shell model calculations as well as the weak-coupling model [4]. It is found that the shell model calculation can well interpret the low-lying states by the particle or hole excitations among $1g_{7/2}$, $2d_{5/2}$, $1h_{11/2}$, $2d_{3/2}$ and $3s_{1/2}$ subshells, and the high-spin levels up to $23/2^-$ could also be qualitatively understood by the weak-coupling approach.

In this work, a much revised level scheme for ^{143}Pm is reported up to an excitation energy of 10535.4 keV. The yrast levels are compared with the weak-coupling calculations, revealing the weak-coupling behavior along the yrast line in ^{143}Pm.

The high-spin states in ^{143}Pm were populated in the reaction of ^{128}Te(^{19}F, 4nγ)^{143}Pm at beam energies between 75 and 95 MeV. The target is an isotropically enriched ^{128}Te metallic foil of 2.2 mg/cm^2 thickness with a 2.3 mg/cm^2 gold backing. The beam was provided by the HI-13 tandem accelerator in the China Institute of Atomic Energy.

The γ-rays de-exciting the high-spin states in ^{143}Pm were studied using the standard in-beam γ-spectroscopy techniques, including excitation functions, Directional Correlations of γ-rays de-exciting Oriented states (DCO ratios) and γ-γ coincidence measurements. Ten high-purity germanium (HPGe) detectors with BGO shields were used. Four of the HPGe detectors were placed at about 90° with respect to the beam direction and the others at about 40°. The standard ^{60}Co, ^{133}Ba and ^{152}Eu sources were used for energy and efficiency calibrations. The detectors have energy resolutions around 2.0–2.5 keV at full width at half maximum for the 1.33 MeV line from ^{60}Co.

The excitation function measurements were performed over a beam energy range of 75–95 MeV with a step of 5 MeV. It was found that the optimum production yield for ^{143}Pm is reached with a beam energy of 82 MeV, which was chosen for the measurements. A total of 200×10^6 coincidence events were recorded for off-line analysis. After gain matching, the data were sorted into a 4096×4096 matrix. The gated spectra with background subtraction were projected for all the detected γ-rays and analyzed very

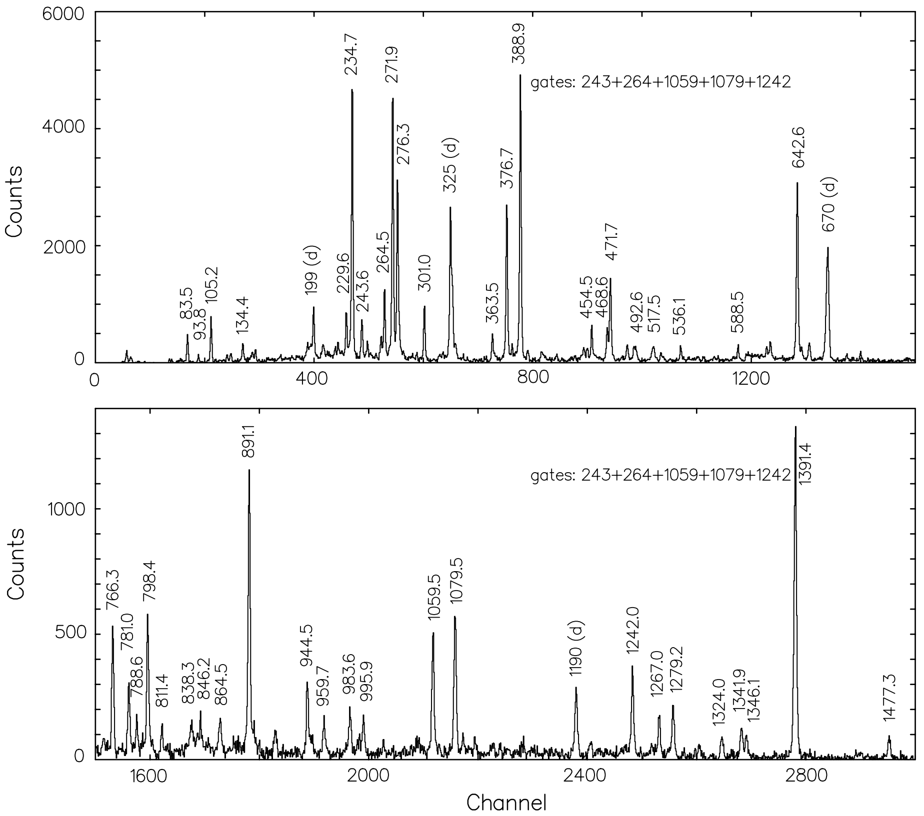

Fig. 1. Added coincidence spectra for ^{143}Pm. The peaks labeled by (d) are doublets.

carefully to establish the level scheme. A summed coincidence spectrum with gates on the 243.6, 264.5, 1059.5, 1079.5 and 1242.0 keV lines is displayed in fig. 1, showing the data quality. The level scheme deduced from the present work is presented in fig. 2. The level scheme below the 4386.0 keV level is consistent with the previous results [2,3]. The high-lying part of level scheme, including 48 new γ-rays and 28 new levels, is built according to the coincidence relationships, intensity balances, crossover transitions, and information given by the γ-ray relative excitation functions. It should be noted that an unobserved 13.5 keV transition, which connects the 8073.2 and 8059.7 keV levels, is supposed based on the γ-γ coincidence relationships.

The anisotropies of the strong 1059.5, 1242.0 and 1279.2 keV γ-rays show stretched quadrupole characters, and these transitions are used as gates for the DCO ratio analysis for the new high-lying transitions. DCO ratios for the 243.6, 670.4, 93.8, 105.2, 471.7 and 891.1 keV transitions are found to be around 0.69, 0.93, 1.94, 1.60, 1.68, and 1.61 against the 1242.0 and 1059.5 keV gates, respectively. The first two values differ distinctly from the last four ones. In the previous work, Prade *et al.* [2] determined a dipole character for the 105.2 and 891.1 keV transitions, which is consistent with our DCO values. In combination with the results of the previous γ-ray angular distribution and conversion electron measurements, the present DCO values and γ-ray anisotropies give the spin and parity assignments to the levels in ^{143}Pm as shown in fig. 2. Parity assignments to some of the levels are suggested on the basis of comparison of the experimental level scheme with the zeroth-order weak-coupling calculations. It should be pointed out that $J = (21/2)$ was assigned to the 3389.7 keV level in ref. [2], but, $J = (23/2)$ for this level is favored on the basis of the present DCO ratio and anisotropy for the 376.7 keV transition. On the other hand, the presence of a parallel cascade composed of the 93.8 and 1279.2 keV transitions, with, respectively, dipole and quadrupole character, is consistent with the $J = (23/2)$ assignment to the 3389.7 keV level.

The high-spin states below the 3601.5 keV level were interpreted by using both the shell model and the cluster-vibration model calculations [2], and most of the levels can also be qualitatively reproduced with a weak-coupling approach [4]. Taking the advantage of simplicity of the weak-coupling calculation, this model is used to interpret the level structure in ^{143}Pm in the present work. In the present work, we have concentrated on the high-lying level structure in ^{143}Pm, so the weak-coupling interpretation of the low-lying level structure is copied from [4], and the similar calculation has been performed for the five high-lying new yrast levels in ^{143}Pm. In this model, it would be expected that states in ^{143}Pm arise from the coupling of $d_{5/2}$ and $h_{11/2}$ protons to ^{142}Nd and $g_{7/2}$ proton holes to ^{144}Sm. The interaction between the core and the protons (or hole) is assumed to be negligible in the calculations (zeroth-order approximation). Thus, the excitation energy of a state in ^{143}Pm is calculated to be the sum of the excitation energy of the core and that of the corresponding valence proton (or proton hole).

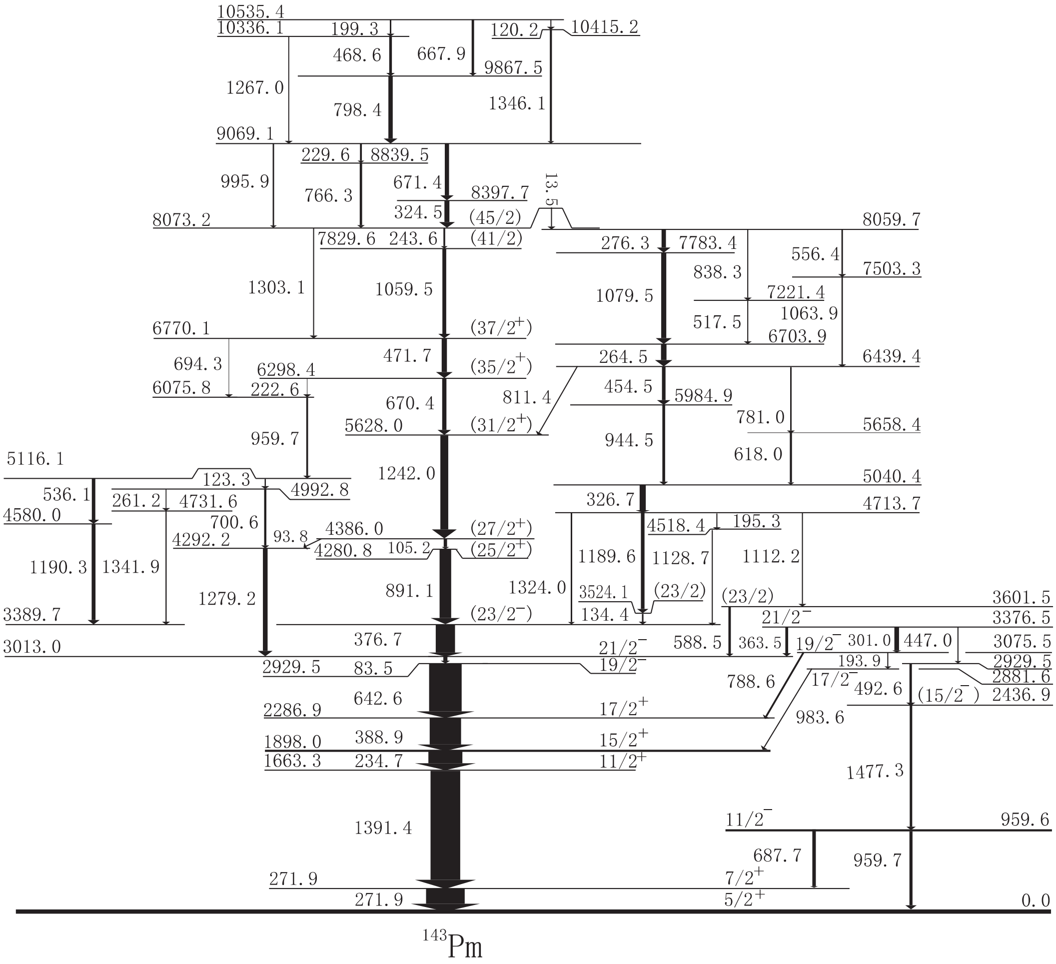

Fig. 2. Level scheme of ^{143}Pm deduced from the present work.

The $d_{5/2}$ and $h_{11/2}$ proton states and $g_{7/2}$ proton hole state were identified at 0, 960 and 270 keV, respectively [5,6]. The calculated level spectrum is presented in fig. 3 and compared with the experimental yrast levels. Generally, the weak-coupling calculation can well reproduce the yrast levels up to $J^\pi = (37/2^+)$ in ^{143}Pm. However, it should be pointed out that the weak-coupling model is not perfect, and its essence is to correlate the states in an odd-A nucleus with those in neighboring even-even nucleus according to their excitation energies. In some cases, the levels observed in the odd-A nucleus have no correspondences in the core. Therefore, the weak-coupling just makes qualitative interpretation on the level structure in the odd-A nuclei. The yrast 6^+ state in ^{142}Nd core is located almost at midpoint of the $21/2^-$ and $23/2^-$ levels in ^{143}Pm, so the authors in ref. [4] suggested that these two levels are originated from coupling of an $h_{11/2}$ proton to the 6^+ core state, although the separation between the $21/2^-$ and $23/2^-$ levels is a little bit large.

The spacings of the level sequence with energies of 959.6, 2436.9, 2929.5 and 3013.0 keV are quite similar to those of the 0^+, 2^+, 4^+ and 6^+ states in the ^{142}Nd core. This similarity is reflected in the calculation by coupling the $h_{11/2}$ proton to the 0^+, 2^+, 4^+ and 6^+ states in the ^{142}Nd core as seen in fig. 3. The part of level scheme below 3601.5 keV was analyzed with the weak-coupling model in details [4]. As expected, the coupling of the $h_{11/2}$ proton to the corresponding states in the ^{142}Nd core dominates the high-lying yrast states in ^{143}Pm because of the high angular momentum character of the $h_{11/2}$ orbit. Wirowski *et al.* [7] suggested that the excited states with $7^- \leq J^\pi \leq 9^-$ in ^{142}Nd are based on the $\pi(d^1_{5/2}h^1_{11/2})$ and $\pi(d^2_{5/2})_0 \otimes \pi(g^{-1}_{7/2}h^1_{11/2})$ proton configurations, and the negative-parity states with $10^- \leq J^\pi \leq 14^-$ have the 4-particle (-hole) configurations of the type $\pi(g^{-1}_{7/2}h^1_{11/2} \otimes d^2_{5/2})$ and $\pi(d^2_{5/2})_0 \otimes \pi(d^1_{5/2}h^1_{11/2} \otimes g^{-2}_{7/2})$. When using weak-coupling model to interpret experimental data, the microscopic composition of the core state should be considered. The five new levels are interpreted through the coupling of an $h_{11/2}$ proton to the core states already involving an $h_{11/2}$ proton excitation. In this case, the valence $h_{11/2}$ proton contributes an angular momentum of 9/2 because of Pauli principle, as shown in fig. 3. Just above the $J = (37/2)$ level, the weak-coupling prediction deviates greatly from the experimental observations. It is likely that the $N = 82$ neutron shell closure is broken and neutrons below the $N = 82$ shell are promoted across the shell gap to participate in the building of the angu-

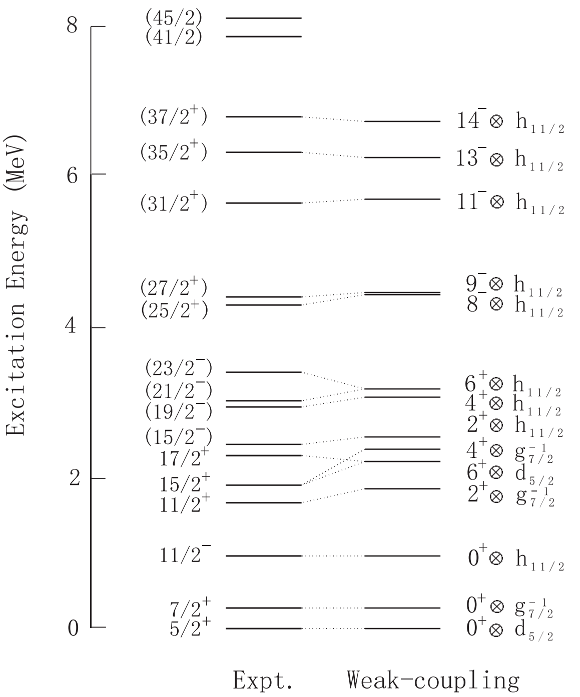

Fig. 3. Comparison of experimentally observed levels in ^{143}Pm with those calculated using the zeroth-order weak-coupling approaches described in the text. The data are taken from refs. [7-9] and the present work.

lar momenta above the $J = (37/2)$ state. The fact that around the $J = (41/2)$ level, the appearance of several high energy transitions supports this suggestion.

In summary, the level scheme of ^{143}Pm has been extended up to 10535.4 keV in excitation energy. The yrast levels up to $J = (37/2^+)$ can be well interpreted by the weak-coupling picture. In order to check the validity of the weak-coupling interpretation, definitive spin-parity assignments to the newly observed levels are required.

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