OCTUPOLE EXCITATIONS IN ^{144}Nd AND ^{146}Sm*

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Level schemes of ^{146}Sm and ^{144}Nd have been studied with GASP. New evidence of collective octupole excitations coupled to low lying shell-model configurations, similar to those of ^{148}Gd, has been obtained.

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Searching for nuclear octupole vibrations in the region of ^{146}Gd, we have studied two even-even nuclei, ^{146}Sm and ^{144}Nd. With the discovery of the quasi-magic character of ^{146}Gd, due to the closure of the neutron shell $N = 82$ and also of the proton sub-shell $Z = 64$ [1], the interest for this part of the chart of nuclides has actually increased.

The nuclei of several regions around a double magic nucleus are theoretically predicted, and experimentally found, to be soft towards octupole vibrations and often collective octupole states are present together with normal shell model states at low excitation energy.

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States corresponding to double octupole excitation have been searched for in the region of ^{208}Pb, but without success. In ^{146}Gd, as in ^{208}Pb, the first-excited state has $I^{\pi} = 3^{-}$, and the strength of the E3 transition to the ground state is nearly the same in the two nuclei ($\approx$ 37 W.u.). We can notice, however, that ^{146}Gd is softer than ^{208}Pb with respect to octupole deformation, as it is shown by the lower excitation energy of the first-excited state (1.58 MeV and 2.62 MeV, respectively).

Probably this is the reason why only in two nuclei of the ^{146}Gd region two octupole phonon states have been identified without doubts. These two nuclei are ^{147}Gd [2] and ^{148}Gd [3–4], having one or two neutrons, respectively, outside the shell closure at $N = 82$. In our experiment, we have investigated the lighter isotones of ^{148}Gd, with two or four proton-holes with respect to the sub-shell closure at $Z = 64$

The nuclei of ^{146}Sm and ^{144}Nd were produced *via* the reactions ^{139}La(^{11}B,4n)^{146}Sm and ^{139}La(^{11}B,α 2n)^{144}Nd at $E(^{11}\mathrm{B}) = 45$ MeV. At this energy, the channels leading to ^{146}Sm and ^{147}Sm share the most of the reaction cross section, while the yield of ^{144}Nd corresponds to about 5% of the total.

Measurements have been performed at the XTU Tandem accelerator of the Laboratori Nazionali di Legnaro, with a thick target (5 mg/cm^2) and a beam current of about 10 particle-nA. Gamma rays were detected with the highly efficient GASP (GAmma SPectrometer) array [5]. GASP consists of 40 Compton-suppressed HPGe detectors placed almost symmetrically over a sphere, with an inner multiplicity-filter containing 80 BGO scintillators. We have collected about 10^9 events in which, at least, three suppressed Ge detectors and two detectors of the multiplicity-filter fired in coincidence.

The results of our analysis, based on doubly-gated coincidence spectra, are summarized in the two level schemes shown in Fig. 1 and Fig. 2, where only levels appreciably populated with our reactions are reported. These level schemes present strong similarities, also if the scheme of ^{146}Sm appears to be richer of levels, due to the more intense reaction channel for its production.

The similarity is particularly impressive for some groups of levels, as those of the third and fourth column: the twelve corresponding levels differ for less then 100 keV in absolute excitation energy, and often the correspondence is better. The analogy between these two sequences suggests the existence of an underlying symmetry.

At the moment, we can give an interpretation for the levels of the first and second column, as the analogy between these columns is not restricted to ^{144}Nd and ^{146}Sm, but extends also to ^{148}Gd. The levels of the first column are interpreted, like in ^{148}Gd [3], as two-neutron shell-model states, and those of the second column as likely candidates for the result of

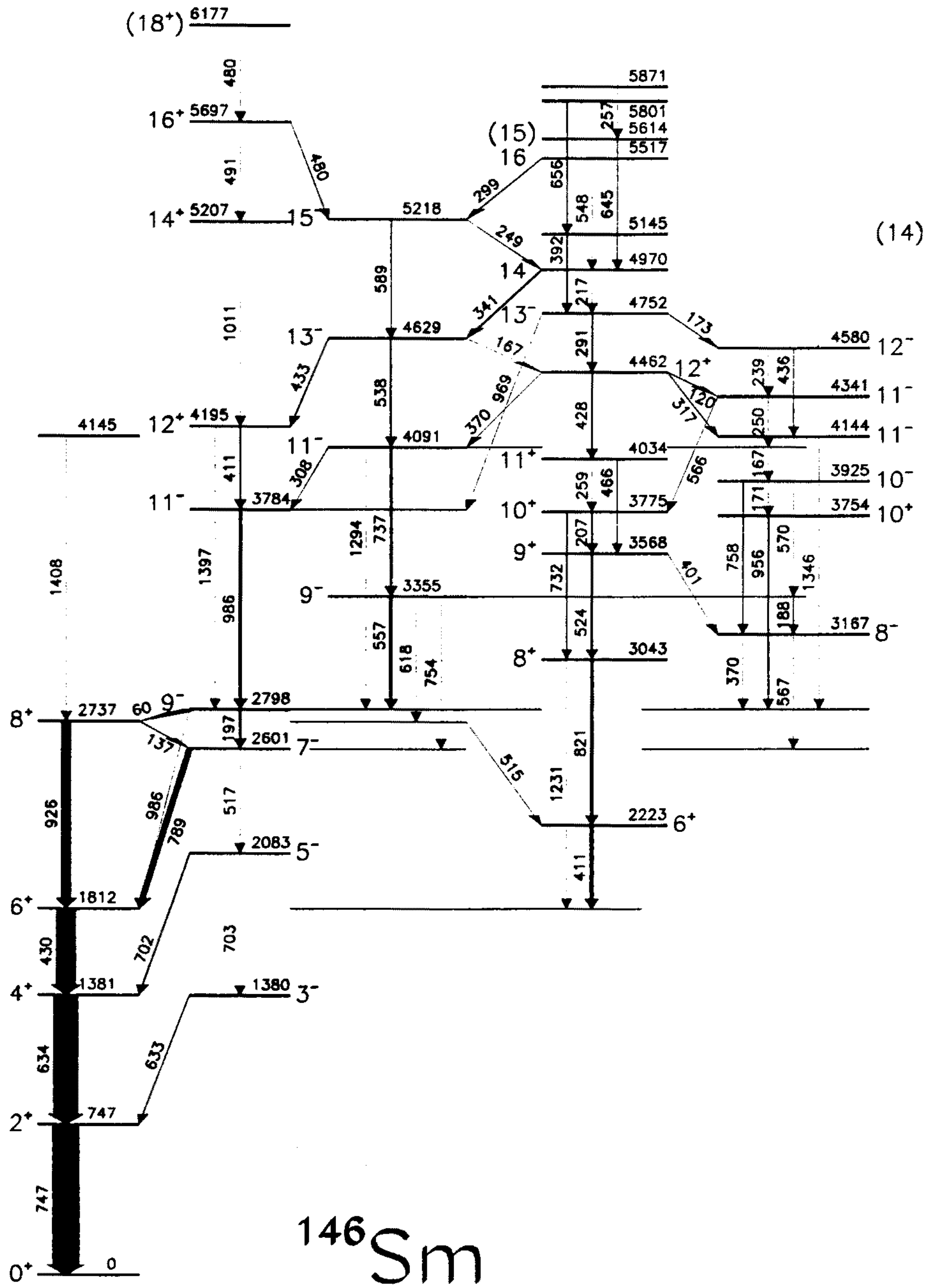

Fig. 1. Level scheme of ^{146}Sm, as observed with the the ^{139XA}La(^{11}B, 4n) reaction.

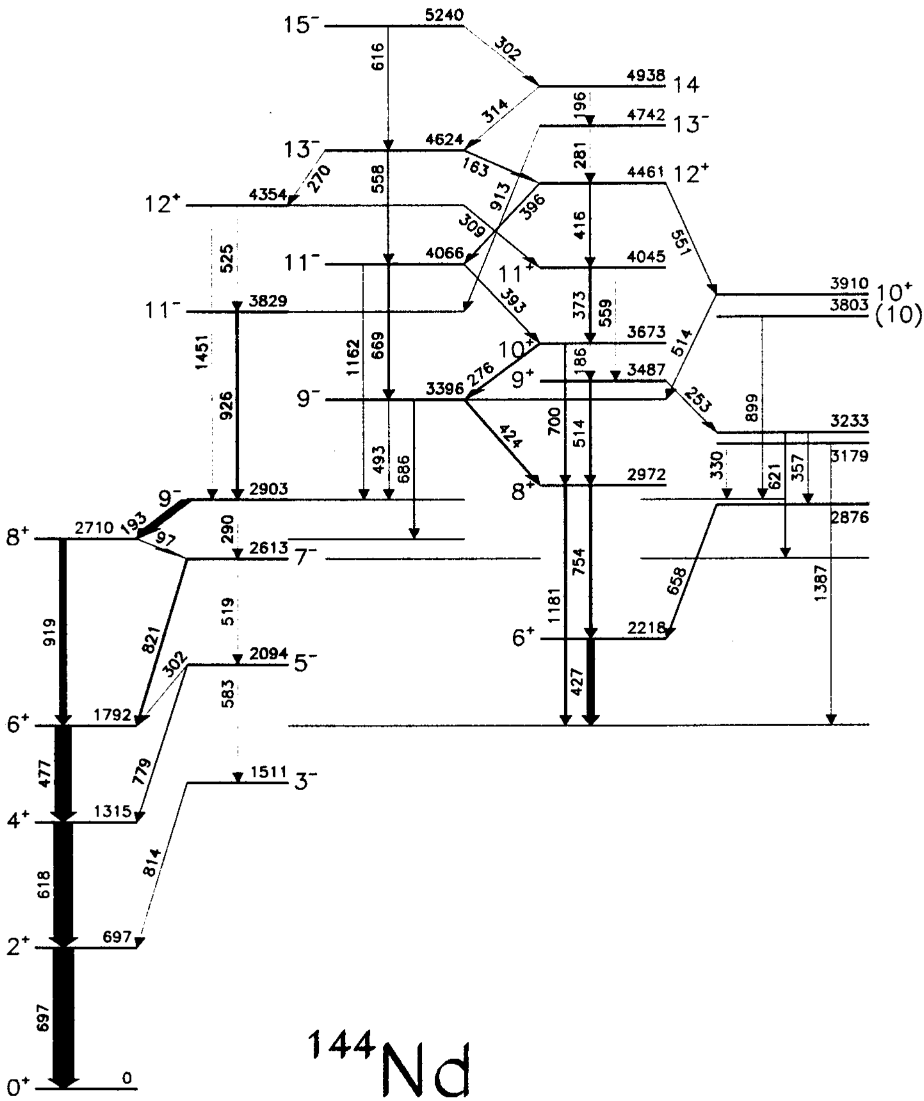

Fig. 2. Level scheme of ^{144}Nd, as observed with the the ^{139}La(^{11}B, α 2n) reaction.

weak coupling, with maximum angular momentum, of one or two octupole phonons to the normal shell-model states of the first column. In Fig. 3, the "two-neutron" levels and the "octupole-coupled" levels of ^{144}Nd, ^{146}Sm are compared with those of ^{148}Gd. For clarity, the levels resulting from the coupling of just one octupole phonon to shell-model states are shown in the second column of each level scheme, while the ones attributed to the coupling of two octupole phonon are reported separately in the third column.

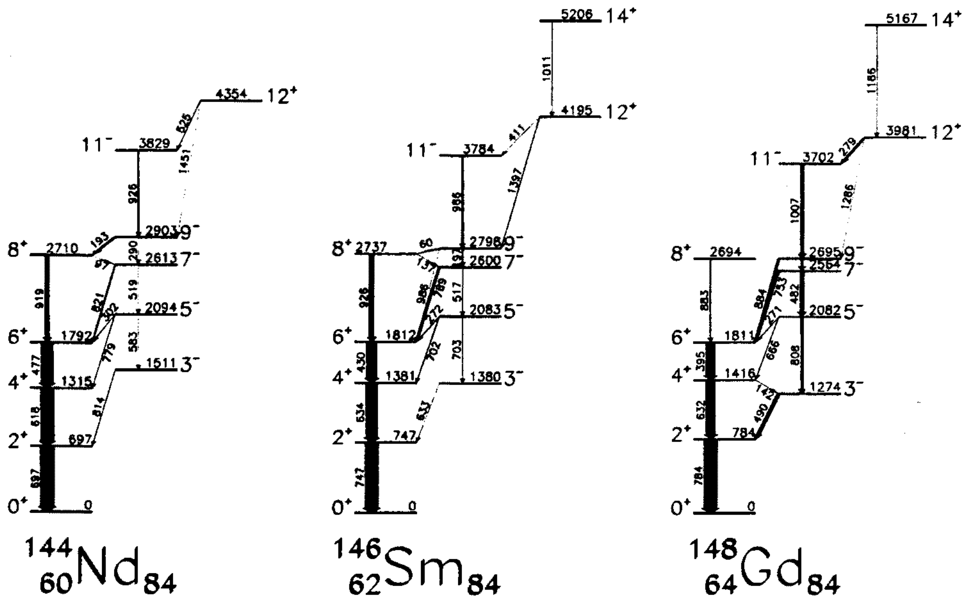

Fig. 3. Partial level scheme of the $N = 84$ isotones ^{148}Gd, ^{146}Sm and ^{144}Nd

In ^{148}Gd, this interpretation of the states of the second column is supported by the large E3 strengths of the transitions from the lowest 3^- level to the 0^+ ground state (42 W.u., from p,p' on a radioactive ^{148}Gd target [6]) and from the lowest 9^- level to the lowest 6^+ level (54 W.u. [4]). The analogy with the situation of ^{148}Gd, suggests that the same mechanism could take place also in ^{146}Sm and ^{144}Nd. In fact the strength of the E3 transition from the 3^- level to the 0^+ level in ^{144}Nd is about 31 W.u. (measured with Coulomb excitation [7]), and we have found, in ^{146}Sm, an E3 transition from the 9^- level to the 6^+ level, which is in competition with E2 and E1 transitions with a branching ratio of the order of $3 \cdot 10^{-2}$. As the "best value" for the half life of the 9^- level is 0.84 ns [8], the resulting E3 strength comes out to be B(E3)$\approx$ 30 W.u. Other E3 transition from the one-octupole-phonon states to the parent zero-phonon states, in all three nuclei, could not be observed, as the competing transitions of lower multipolarity are energetically favored: *e.g.*, the expected branching ratio for the E3 transition from the 9^- level to the 6^+ level in ^{144}Nd would be about $2 \cdot 10^{-3}$, and could hardly be seen, even with the high-efficiency γ spectrometers available today.

The 12^+ level in the third column of the ^{148}Gd level scheme is interpreted [3] as the result of the stretched coupling of two octupole phonons to the 6^+ level of the first column. This interpretation is supported by the large strength (B(E3) = 77 W.u., according to ref. [4]) of the E3 transition de-exciting the 12^+ level to the parent (one octupole-phonon less) 9^- state. We suggest that the same interpretation can be valid also for ^{146}Sm and ^{144}Nd and, in this case, the 12^+ levels shown in the third column of the level schemes, can be considered to be likely candidates as partners of the $I^\pi = 12^+$, two-octupole phonon-state of ^{148}Gd.

In fact, the spin of the 4195 keV level of ^{146}Sm appears to be $I = 12$ (at variance with earlier results [8]), as both the 433 keV transition from the 4629 keV, $I = 11^-$ level and the 411 keV transition to the 3784 keV, $I = 11^-$ level have angular asymmetries typical of stretched dipoles. In addition, a weak 1397 keV transition (see Fig. 4) has been observed in $\gamma - \gamma - \gamma$ coincidences, with a first gate on selected transitions feeding the 4195 keV level and a second one on several transitions of the cascade coming from the 2798 keV level (the intensity of the cross-over branch, of the order of some percents, is much larger than that expected for the sum peak of the 411 keV and 986 keV transitions). This transition is therefore an E3, and the parity of the parent state is positive.

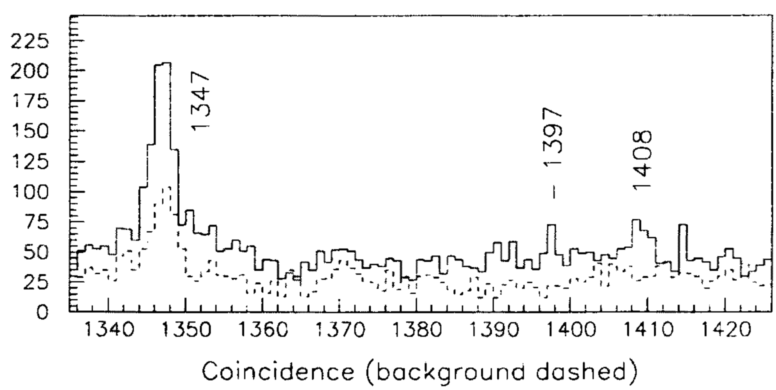

Fig. 4. Triple coincidence spectrum at 34°, doubly gated on selected ^{146}Sm γ lines, showing the $12^+ \to 9^-$, 1397 keV, transition.

The level at 4354 keV in ^{144}Nd is new, and its spin $I = 12$ can be assigned with similar arguments (although with some more difficulty, as the reaction channel leading to ^{144}Nd is weaker). Moreover, a 1450 keV transition has been observed to feed the 2903 keV, $I = 9^-$ state. This line seems to be double, and there are some indications (see Fig. 5) that its higher-energy side (1451-1452 keV, corresponding almost exactly to the

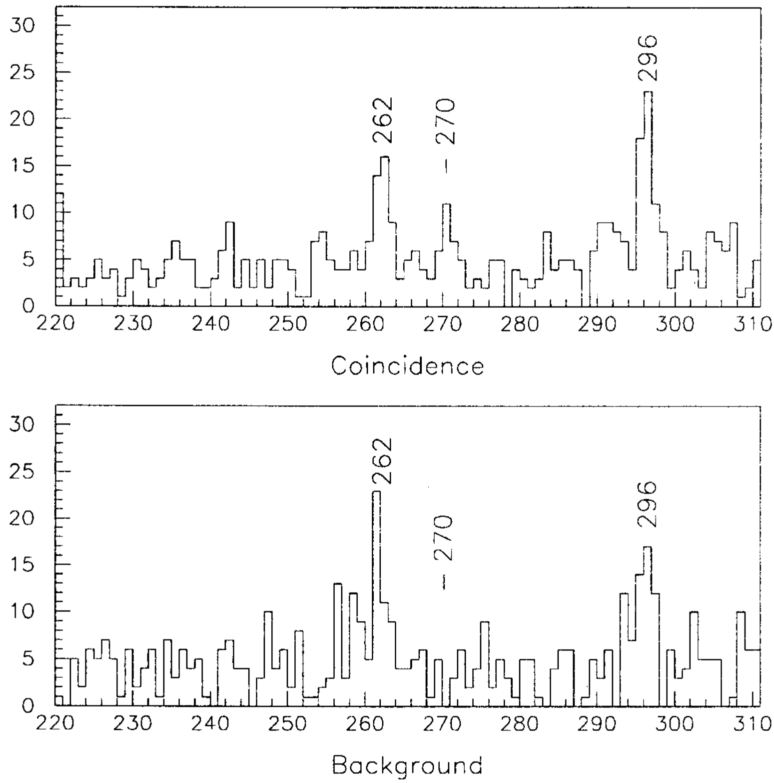

Fig. 5. Triple coincidence spectra showing the coincidence of the 1451 keV transition of ^{144}Nd with the 270 keV line that feeds the 12^+ octupole level. "Coincidence" spectrum obtained with one multiple gate on the four low-lying most intense γ rays of ^{144}Nd and a second gate on 1451-2 keV γ rays. The 270 keV line is not present in the "background" spectrum.

cross-over) is in coincidence with the 270 keV transition that feeds the 4354 keV level. In this case, this transition should be E3 and the parity of the parent state is positive. Measurements are in program with a more selective reaction, in order to make sure the spin and parity assignment to the 4354 keV level and to measure — if possible — the partial life time for the cross-over transition.

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