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Low-lying vibrational states of ^{145,147,149}Nd

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Abstract. The fragmented neutron states in ^{145,147,149}Nd detected through ^{144}Nd(d, p) and ^{148,150}Nd(d, t) reactions can be accounted for in terms of quasiparticles coupled with anharmonic vibrator model. The wave functions, obtained from diagonalisation of the Hamiltonian matrices are utilised to calculate B(E2), B(M1) and branching ratios in ^{145,147}Nd. The calculated results are discussed in the light of the recent experimental findings.

Keywords. Nuclear structure; anharmonic vibrator model; quasi-particles; energy level scheme; spectroscopic factors; branching ratios.

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1. Introduction

It has been shown (Majumdar 1983) that neutron states (N = 50–82; 82–126 shell) coupled with the quadrupole and octupole phonon states of ^{144,148,150}Nd can distinctly explain the fragmentation of a few low-lying spin states of the ^{145,147,149}Nd nuclei. A comprehensive study of the structure of the low-lying spin states of these odd-A nuclei has been made through the quasiparticle coupled with the anharmonic vibrator model.

The study of the nuclei outside the well-established deformed regions stems from the concept of co-existence of spherical and deformed states (Garrett *et al* 1976; Kleinheinz *et al* 1974). Around the mass region $A \simeq 150$, the transition from the spherical to the deformed shape can be got by studying the low energy spectra, B(E2) values and the giant dipole resonances. Various experiments on both stripping and pick-up reactions were carried out to understand the nature of high and low spin states of $^{145-149}$Nd (Løvhøiden *et al* 1980; Hillis *et al* 1975; Straume and Burke 1977; Burke *et al* 1973; Wiedner *et al* 1967). From the available experimental data, it can be concluded that specially the low spin states of these Nd-isotopes cannot be purely single hole or particle in nature, rather the single particle or hole strengths are densely distributed over them which inherently suggest (Løvhøiden *et al* 1980) coupling of these states to vibrational states of the neighbouring even-even nuclei. This is a characteristic feature observed in transitional regions. This picture seems to be rather incongruous with the structure of the $11/2^-$ state in ^{147,145}Nd. From ^{148,146}Nd (^{3}He, α) reaction Sekiguchi *et al* (1977) have detected fragmentations of the $11/2^-$ state in ^{147,145}Nd within the excitation region of 1·5–4·5 MeV. These states are associated with the Nilsson orbitals originating from the spherical $1h_{11/2}$ hole state *i.e.* the result of deformation of these nuclei is the direct consequence of the fragmented $1h_{11/2}^{-1}$ states in ^{145,147}Nd into several Nilsson states.

Based on these experimental observations and guided by the information that there exist spherical and deformed states in these odd-A Nd isotopes, we have undertaken a thorough analysis of the low spin and energy states within the framework of quasiparticle phonon coupling model calculation. The interpretation of ^{143}Nd nucleus from an unified model (Veefkind *et al* 1975) seems to be an explicit success. But these nuclei lie in the vicinity of the deformed region. Also the energy level spectra of ^{144,148,150}Nd show the anharmonic nature of these nuclei. So the simple vibrational aspects of the core nuclei are rather forbidden. In our case, as there are three, five and seven valence neutrons, over the magic $N = 82$ core nucleus ^{142}Nd, in ^{145,147,149}Nd respectively, the effect of pairing interaction is to be incorporated into the unifield model calculation. The quasiparticle states are coupled with quadrupole (one and two phonon) and octupole (one phonon) vibrational states of the core nuclei to understand the low energy spectra of the three Nd-isotopes. Recently (Dias and Krmpotic 1982; Dragulescu *et al* 1984) cluster-phonon coupling model was applied to understand the few low-lying levels in ^{145}Nd but it failed to reproduce satisfactory agreement with experimental observations. As far as our knowledge permits, no other theoretical calculation exists in literature as yet for these three Nd-isotopes except the one mentioned above.

2. The model

The model adopted in the present work has been discussed in our work on ^{211}Po (Mukherjee *et al* 1982). The Hamiltonian of the system can be written as (Bohr and Mottelson 1975)

$$H = H_{\mathrm{vib}} + H_p + H_{\mathrm{int}}, \tag{1}$$

where H_{vib} gives the vibrational energy of the core. H_p is the Hamiltonian for the neutron in the average shell model potential and H_{int} represents the core-particle interaction

$$H_{\mathrm{int}} = -\sum_{\lambda=2}^{3} X_\lambda \hbar\omega_\lambda \sum_{\mu=-\lambda}^{\lambda} [b_{\lambda\mu} + (-1)^\mu b^*_{\lambda\mu}] Y_{\lambda\mu}(\theta, \phi), \tag{2}$$

where X_λ is the strength of the coupling, $\hbar\omega_\lambda$ is the energy of the phonon for the λ-mode vibration of the collective core and $b_{\lambda\mu}$ and $b^*_{\lambda\mu}$ represent the usual annihilation and creation operators for the phonons, respectively.

In order to evaluate the eigenvalues for the Hamiltonian (1) we take the wave function for J spin state as

$$\psi_J = \sum_{Rlj} a_{Rlj} \mid \{(N_2 R_2, N_3 R_3) R; (nl\tfrac{1}{2}) j\}_M^{J,\pi} \rangle, \tag{3}$$

where j is the angular momentum of the particle, R_2 and R_3 are the phonon angular momenta corresponding to the number of quadrupole phonons N_2 and octupole phonons N_3. R is the coupled phonon angular momentum of R_2 and R_3. For the present calculation $N_2 = 1$, 2 and $N_3 = 1$ respectively. In (3) the summation over j includes neutron shell model states satisfying the relation $J = R + j$. The matrix elements of H_{int} in this representation are given by

$$\begin{aligned}
&\langle N_2R_2,\, N_3R_3;\, R, j;\, J\,|H_{\text{int}}|\,N'_2R'_2,\, N'_3R'_3;\, R', j';\, J\rangle \\
&= \sum_{\lambda} X_\lambda \hbar\omega_\lambda\, (-1)^{R+j'-J}\, [2(2R+1)(2j+1)(2R'+1)(2R_\lambda+1)]^{1/2} \\
&W(R'Rj'j;\, \lambda J)\begin{pmatrix} j & \lambda & j' \\ \frac{1}{2} & 0 & \frac{1}{2} \end{pmatrix}[\delta_{\lambda,2}\, W(R'RR'_\lambda R_\lambda;\, \lambda R'_3) \\
&(-1)^{R'_\lambda - R - R'_3 - \lambda} + \delta_{\lambda,3}\, W(R'RR'_\lambda R_\lambda;\, \lambda R'_2)(-1)^{R'+R_\lambda - R'_2 - \lambda}] \\
&\delta_{N_\eta N'_\eta}\, \delta_{R_\eta R'_\eta}[\delta_{N_\lambda, N'_\lambda + p} \langle N_\lambda R_\lambda \| b^*_\lambda \| N'_\lambda R'_\lambda\rangle + \delta_{N'_\lambda, N_\lambda + p} \\
&(-1)^{R_\lambda - R'_\lambda}\langle N'_\lambda R'_\lambda \| b^*_\lambda \| N_\lambda R_\lambda\rangle]\,(U_jU_{j'} - V_jV_{j'}),
\end{aligned} \tag{4}$$

where the symbols used have their usual meanings. The subscripts η in N_η and R_η assume the value 2 when $\lambda = 3$ and vice-versa and $p = \Delta N_\lambda$ where N_λ is the phonon number for the λ-mode vibration. The diagonal matrix elements of the Hamiltonian (1) are the sum of the quasiparticle energy ε_{nlj} and the energy of the core. The anharmonicity of the core energy levels (Castel *et al* 1971) is described by v, so that quadrupole vibrational energies of the two phonon states are given by $(2+v)\hbar\omega_2$. v is estimated from the spectrum of the core nucleus. Also in the anharmonic approximation the matrix elements $\langle b_2^* \rangle$ for $N_2 = 0$ and 2 exist. Here the values of $\langle b_2^* \rangle$ between the phonon states have been taken from the tabulated values of Bohr and Mottelson (1975). The $\langle b_3^* \rangle$ has been kept at its harmonic value. The spectroscopic factor of a state $(J = j)$ is the absolute square of that coefficient in its wave function which corresponds to a pure hole or particle state,

$$\begin{aligned}
S(l,j) &= V_j^2\,|a_{0lj}|^2, &&\text{for hole state} \\
&= U_j^2\,|a_{0lj}|^2, &&\text{for particle state}
\end{aligned}$$

$S(l,j)$ obeys the sum rule $\sum_K S_K(l,j) = 1$, where K differentiates the state of the same spin and parity.

The expressions for the static and dynamic electromagnetic multipole moment operators have been taken from Bohr and Mottelson (1953).

3. Discussion

Following Blankert *et al* (1981) single quasiparticle energies for the three nuclei have been estimated from the reaction experiment by

$$\varepsilon_j = \frac{\sum_i E^i_{lj} S^i_{lj}}{\sum_i S^i_{lj}}$$

where E^i_{lj} is the excitation energy of the ith lj state and S^i_{lj} is the spectroscopic factor. For ^{147,149}Nd V_j^2 have been ascertained from the pick-up reaction spectrum (Straume and Burke 1977; Løvhøiden *et al* 1980) by

$$V_j^2 = \sum_i S^i_{lj}\,(\text{exp})\,|\,(2j+1)$$

In ^{145}Nd U_j^2 have been estimated from stripping reaction data (Hillis *et al* 1975) by the relation

$$U_j^2 = \sum_i S_{ij}^i \text{ (exp)}.$$

The number of quasiparticle states included in the calculations for the three nuclei have been kept fixed in view of the number of unique spin states obtained through reactions. This has been adopted because of the easy estimation of the energy of the quasiparticle state by the relation depicted above. The values of V_j^2 and U_j^2 for ^{147}Nd and ^{145}Nd have been kept fixed at the experimental values. Only ε_j, X_2 and X_3 have been varied to optimize the theoretical energies and spectroscopic factors with the corresponding experimental estimates. In view of these the number of parameters for ^{147}Nd and ^{145}Nd is eleven and six respectively. For ^{149}Nd, the number of actual parameters is also 11 including X_2 and X_3 if we allow 30% uncertainties for the estimations of V_j^2 from experiment (Løvhøiden *et al* 1980). The energy level schemes of ^{144}Nd (Snelling and Hamilton 1983), ^{148}Nd (Nuclear Data 1967) and ^{150}Nd (Nuclear Data Sheets 1976) have been kept in view to include the anharmonic nature of the cores so that quadrupole vibrational energies of one and two-phonon states correspond to the experimental estimates. E2, M1 transition rates as well as branching ratios are evaluated taking $e_n^{\text{eff}} = 0{\cdot}5\text{e}$, $eZ(\hbar\omega_2/2c_2)^{1/2} = 6{\cdot}5\text{e}$, $g_R = Z/A = 0{\cdot}41$, $g_l = 0$, $g_s^{\text{eff}} = 0{\cdot}5$, $g_s^{\text{free}} = -1{\cdot}91$ (Dias and Krmpotic 1982). The matrix elements of $\langle r^2 \rangle$ for calculation of B(E2) rates are known from wave functions deduced from Woods-Saxon potential (Dias and Krmpotic 1982). Though $\langle r^2 \rangle = \frac{3}{5}(1{\cdot}2\ \text{A}^{1/3})^2\ \text{fm}^2$ is a very good approximation. The $\hbar\omega_2$ and $\hbar\omega_3$ for three more nuclei have been taken from the positions of 2_1^+ and 3_1^- states determined from Coulomb excitation and inelastic scattering experiments (Hillis *et al* 1977).

3.1 *The nucleus* ^{147}*Nd*

From ^{146}Nd (n, γ) reaction (Roussille *et al* 1975), and ^{146}Nd (d, p) reaction (Wiedner *et al* 1967) the level scheme of ^{147}Nd is known. The ^{148}Nd (d, t) reaction using 12 MeV deuterons (Straume and Burke 1977) reveals the fragmentations of several positive and negative parity neutron hole states. Recently, detailed information about the population of the neutron hole states are known from ^{148}Nd (d, t) and ^{148}Nd $(^3\text{He}, \alpha)$ reactions (Løvhøiden *et al* 1980). We have compared our theoretical level scheme with the ^{148}Nd (d, t) reaction spectrum of Løvhøiden *et al* (1980) and restricted our calculation up to 1·6 MeV excitation energy of ^{147}Nd. The experimental energy values involve uncertainties to the extent of ± 5 keV and the estimated uncertainty in the spectroscopic factor is ~30%.

Matrices for the $5/2^-, 7/2^-, 9/2^-, 1/2^-, 3/2^-, 11/2^-, 1/2^+, 3/2^+$ and $13/2^+$ spin states have been constructed by coupling $3s_{1/2}$, $2d_{3/2}$, $2d_{5/2}$, $3p_{1/2}$, $3p_{3/2}$, $2f_{5/2}$, $2f_{7/2}$, $1h_{9/2}$, $i_{13/2}$ and $1h_{11/2}$ neutron quasiparticle states with one and two quadrupole and one octupole vibrations of ^{148}Nd core. The matrices have been diagonalised to get eigen values and eigen vectors. The values of ε_j, X_2, X_3 and V_j^2 adopted for the calculations are shown in table 1. Only X_2, X_3 and ε_j have been optimized to get best fit of the theoretical level scheme with the experiment (Løvhøiden *et al* 1980). Almost all the states of this isotope have been located within 0–1·7 MeV (figure 1). Three fragments of $7/2^-$ state have been identified against two from experiment. $5/2^-$ (ground state) and $5/2^-$ (0·2 MeV) correspond to experimental 0·13 and 0·0 MeV states inspite of the

Table 1. Values of ε_j, V_j^2, U_j^2, X_2 and X_3 for $^{147-149}$Nd adopted for calculation.

Neutron state n_{lj}		$3p_{1/2}$	$3p_{3/2}$	$2f_{5/2}$	$2f_{7/2}$	$1h_{9/2}$	$1h_{11/2}$	$3s_{1/2}$	$2d_{3/2}$	$2d_{5/2}$	$1i_{13/2}$
	^{147}Nd: $X_2 = 0·5$; $X_3 = 0·3$										
ε_j (MeV)	Present work	0·60	0·45	0·13	0·10	0·30	1·45	1·35	1·40	1·60	0·93
	Exp*	0·52	0·62	0·23	0·11	0·19	1·46	1·40	1·20	1·70	0·93
V_j^2	Present work	0·12	0·20	0·10	0·26	0·08	0·17	0·62	0·52	0·09	0·04
	Exp*	0·12	0·20	0·10	0·26	0·08	0·17	0·62	0·52	0·09	0·04
	^{145}Nd: $X_2 = 0·5$; $X_3 = 0·3$										
ε_j (MeV)	Present work		0·80	1·20	0·00	0·90					1·10
	Exp**		1·30	1·70	0·00	0·60					1·40
U_j^2	Present		0·89	0·98	0·53	0·73					0·39
	Exp**		0·89	0·98	0·53	0·73					0·39
	^{149}Nd = $X_2 = 0·7$; $X_3 = 0·4$										
ε_j (MeV)	Present			0·08	0·20		0·70	1·00	0·80		
	Exp†			0·10	0·50		1·20	0·90	0·90		
V_j^2	Present work			0·03	0·12		0·20	0·60	0·40		
	Exp†			0·04	0·18		0·29	0·70	0·46		

The uncertainties in ε_j and V_j^2 are * ± 2 keV and ±25% respectively (after Straume and Burke 1977); † ±5 keV and 30% respectively (after Løvhøiden *et al* 1980). **Those for ε_j and U_j^2 are 5–10 keV and 15% respectively (after Hillis *et al* 1975).

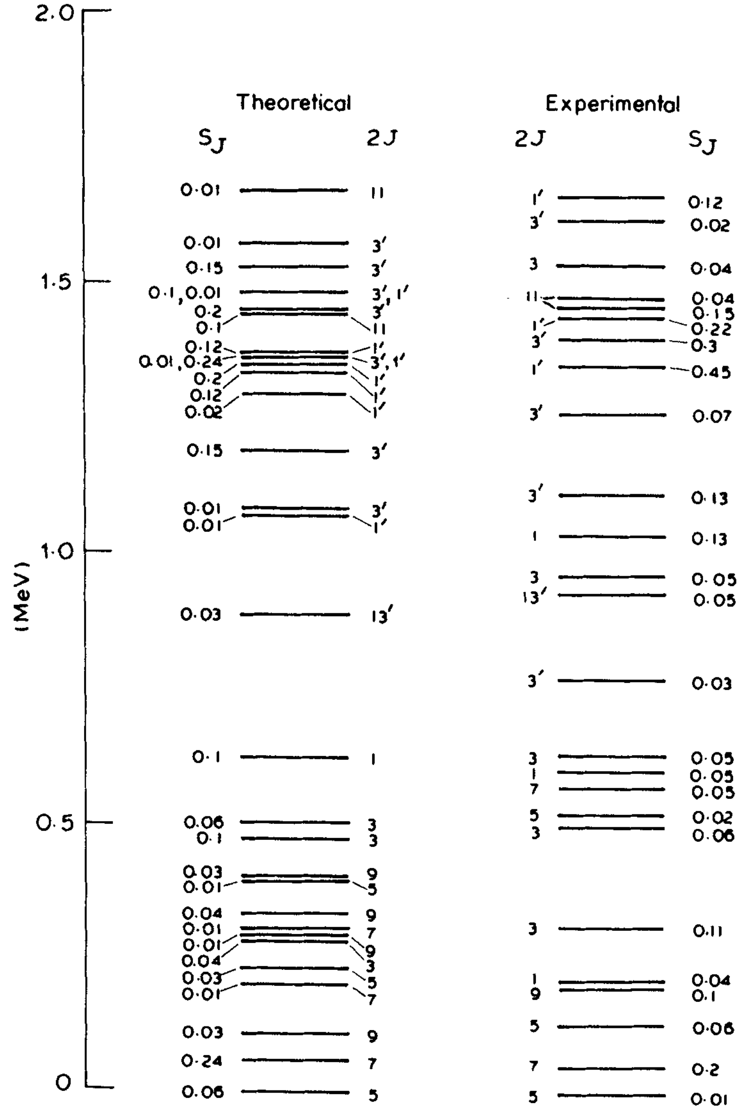

Figure 1. Energy level diagram with spectroscopic factors for various spin states of ^{147}Nd. The dashed numbers (1, 3) indicate positive parity states.

inclusion of 30% uncertainties with the experimental measurements. Only two fragments of $11/2^-$ states (1·4 and 1·7 MeV) have been located against two detected through ^{148}Nd (^{3}He, α) reaction (Løvhøiden *et al* 1980). The results of $11/2^-$ and $13/2^+$ states indicate no remarkable fragmentations giving the signature of the obscured vibrational structures of these two states within 1·7 MeV. A bunch of fragmented states of $3/2^+$ and $1/2^+$ have been located within 1–1·6 MeV against 0·7–1·7 MeV from experiment. We have not taken $5/2^+$ state in our calculation as the splitting revealed from experiment within 1·7 MeV region, is not appreciable. A fragment of $3/2^-$ state is located at 1·56 MeV from experiment which our calculation fails to reproduce. The single particle nature of this state is questionable from the present model.

The nanosecond lifetimes of several states in ^{147}Nd (Hammaren *et al* 1980) have been calculated using (d, p, γ) reaction in ^{146}Nd. From these B(E2) and B(M1) values are obtained with the theoretical conversion coefficients (Hager and Seltzer 1968). We have compared our B(E2) and B(M1) values with these experimental results. From table 2, it is seen that almost all the B(E2) transitions rates are in close proximity with our theoretical estimates. A comparison with the values obtained from particle-rotor model calculation shows that better agreement has been obtained particularly with $5/2_2^- \rightarrow 5/2_1^-$, $9/2_1^- \rightarrow 7/2_1^-$ and $1/2_1^- \rightarrow 5/2_1^-$ B(E2), B(M1) transition rates. Table 3 reproduces the value of ground state magnetic moment.

3.2 *The nucleus* ^{145}*Nd*

Information of ^{145}Nd levels with spectroscopic factors have been obtained through ^{144}Nd (d,p), ^{144}Nd $(\alpha, {}^3\mathrm{He})$ and ^{146}Nd (p,d) reactions (Hillis *et al* 1975). From ^{144}Nd $(\alpha, {}^3\mathrm{He})$ reaction (Bingham *et al* 1973) $13/2^+$ (1·11 MeV) and $7/2^-$ (ground state) states are known. Several negative and positive parity spin states within 0 to 3·153 MeV excitation region of ^{145}Nd have been obtained through ^{146}Nd $({}^3\mathrm{He}, \alpha)$ reactions (Løvhøiden *et al*

Table 2. B(E2) and B(M1) values for several transitions in ^{147}Nd.

		B(E2) (10^{-2} $e^2 \cdot b^2$)			B(M1) (10^{-3} μ_N^2)		
J_i^π	J_f^π	Exp†	Theoret.†	Theoret.	Exp†	Theoret.	Theoret.
$7/2_1^-$	$5/2_1^-$	$12 \pm ^{15}_{8}$	6	5·4	$10 \pm ^{5}_{3}$	45	52
$5/2_2^-$	$5/2_1^-$	$20 \pm ^{30}_{10}$	6	21·6	$2 \pm ^{3}_{1}$	50	0·5
$5/2_2^-$	$7/2_1^-$	$> 70 \pm ^{220}_{60}$	13	6·5	$> 17 \pm ^{26}_{9}$	9	23
$9/2_1^-$	$7/2_1^-$	$60 \pm ^{30}_{20}$	2	20·8	$8 \pm ^{4}_{2}$	0·004	16·2
$1/2_1^-$	$5/2_1^-$	$0{\cdot}09 \pm ^{0{\cdot}04}_{0{\cdot}03}$	19	0·2	—	—	—
$1/2_1^-$	$5/2_2^-$	$43 \pm ^{15}_{11}$	18	2·0	—	—	—

†Hammaren *et al* (1980).

Table 3. Ground states magnetic and quadrupole moments of ^{145}Nd and ^{147}Nd.

	$\mu(n, m)$	Q(eb)
^{145}Nd	−0·90(−0·66)	−0·10(−0·25)
^{147}Nd	0·752(0·577)	—

(The values in parentheses indicate experimental estimates involving no uncertainty in the predicted values).

1980). The fragmentation of the 11/2$^-$ hole states has been obtained from ^{146}Nd (^{3}He, α) reaction (Sekiguchi *et al* 1977; Løvhøiden *et al* 1980; Ramsøy *et al* 1984). The low-lying states of ^{145}Nd have been recently studied by means of Coulomb excitation with ^{16}O and α-particles (Dragulescu *et al* 1984) and by measuring γ-rays following the ^{146}Nd (^{3}He, α) pick up reaction (Ramsøy *et al* 1984). As we are mainly interested with the low spin states of this isotope, only the experimental results based on the (d, p) reaction (Hillis *et al* 1975) have been kept in view to understand the structure of the low-lying states of ^{145}Nd up to 1·8 MeV energy. The experimental uncertainties on the energies of the excited states are estimated at 5–10 keV. Also the experimental uncertainty in the determination of spectroscopic factors due to estimation of absolute cross-sections is 15%.

We have vouched upon only those excited states for which assignments have been done quite unambiguously. 3/2$^-$, 5/2$^-$, 7/2$^-$, 13/2$^+$ and 9/2$^-$ states of ^{145}Nd have been set up by the coupling of $3p_{3/2}$, $2f_{5/2}$, $2f_{7/2}$, $1h_{9/2}$ and $1i_{13/2}$ quasiparticle with the quadrupole (one phonon and two phonon) and octupole (one phonon) vibrational states of ^{144}Nd core. The X_2, X_3 and ε_j values have been adjusted to obtain corroboration of energy eigenvalues and spectroscopic factors with the corresponding experimental estimates after diagonalisation of the matrices. The adopted values of X_2, X_3, U_j^2 and ε_j are given in table 1. From the energy level scheme we see (figure 2), that altogether seven fragments of 5/2$^-$ (0·6–1·7 MeV) have been reproduced. Though the assignments of 1·15, 1·25, 1·33, 1·59, 1·65, 1·69 MeV states have been identified tentatively to be 5/2$^-$ through l-transfers the justification for the assignment has been revealed from our calculations as no further splitting of the $2f_{7/2}$ state has been obtained except the ground state. The number of fragmented 3/2$^-$ states are comparatively larger than that detected through experiment. The 0·779 MeV, and 1·889 (3/2$^-$) states correspond to the calculated 0·82 and 1·8 MeV. The identifications of these 3/2$^-$ states have been confirmed from the present work as the spin estimations of all these states have been done tentatively. Two fragments of 9/2$^-$ states have been obtained instead of only one confirmed 9/2$^-$ state at 0·747 MeV from experiment. This state corresponds to the 0·88 MeV state. No appreciable splitting of 13/2$^+$ state has been noticed from our calculation within the span of 1·8 MeV excitation energy region. We have not considered the 11/2$^-$ state as our calculation is based on ^{144}Nd (d, p) reaction (Hillis *et al* 1975) where only particle states have been excited. The level scheme of this nucleus within the span of 1·5 MeV energy on the basis of the cluster-phonon coupling model as regards of energies and spectroscopic factors (Dragulescu *et al* 1984) and energies (Dias *et al* 1982) for the few spin states are in poor agreement with the experimental findings. In view of this limitation from cluster-phonon coupling model agreement with the experimental results for the excited states in ^{145}Nd from the present model is quite satisfactory.

E2 and M1 transition rates are calculated as in ^{147}Nd. Using the calculated E2, M1 transition rates, branching ratios of the transitions originating from the same level are also calculated in relevant cases. The calculated and experimental branching ratios (Hillis *et al* 1975) are listed in table 4 and the static, electric and magnetic moments of the ground state are shown in table 3.

3.3 *The nucleus* ^{149}*Nd*

From (d, t) and (^{3}He, α) reactions (Løvhøiden *et al* 1980), fragmentation of several positive and negative parity hole states is detected. The experimental energy values for

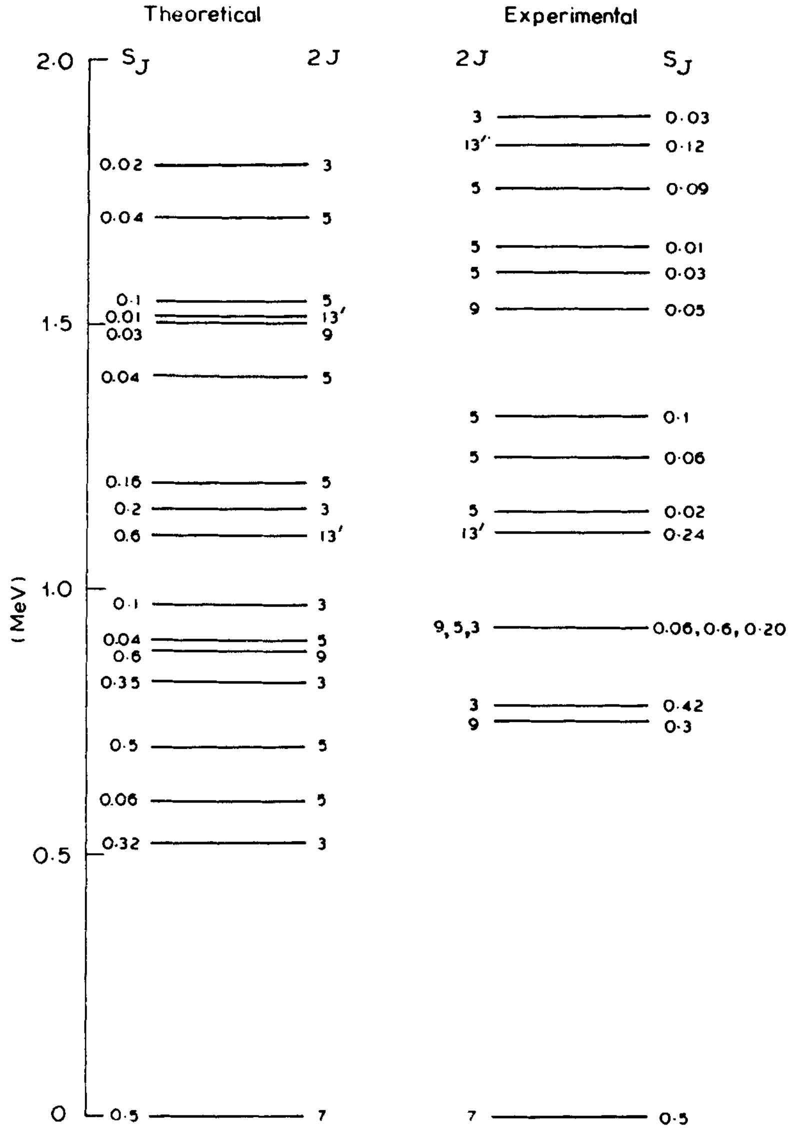

Figure 2. Energy level diagram with spectroscopic factors for various spin states of ^{145}Nd. The dashed number (1, 3) indicates positive parity state.

the excited spin states involve uncertainties to the extent of ±5 keV and the estimated uncertainty in the spectroscopic factors is $\sim 30\%$. As the fragmentations of the $9/2^-$ and $3/2^-$ states are not distinct in the low excitation energy region we have considered only $3/2^+$, $1/2^+$, $11/2^-$, $7/2^-$ and $5/2^-$ states in our calculation. So the quasiparticle states chosen for this nucleus are the $3s_{1/2}$, $2d_{3/2}$, $2f_{5/2}$, $2f_{7/2}$ and $1h_{11/2}$ states. As the estimations for the energies of $3p_{3/2}$ and $1h_{9/2}$ states cannot be made correctly, we have excluded these states from the assignment of the quasiparticle states. Matrices for $3/2^+$, $1/2^+$, $11/2^-$, $7/2^-$ and $5/2^-$ states have been set up by coupling quadrupole one and two

Table 4. Calculated and experimental branching ratios for several transitions in ^{145}Nd.

		Calculated			Branching ratio	
J_i^π	J_f^π	$P(E2)$ (S^{-1})	$P(M1)$ (S^{-1})	$P_{\mathrm{tot}}(\mathrm{S}^{-1})$	Theoret.	Exp.†
$5/2_4^-$	$5/2_1^-$	$3{\cdot}06 \times 10^{10}$	$1{\cdot}32 \times 10^9$	$3{\cdot}19 \times 10^{10}$	1·1	3·25
$5/2_4^-$	$3/2_1^-$	1×10^9	$2{\cdot}84 \times 10^{10}$	$2{\cdot}94 \times 10^{10}$	1	1
$5/2_3^-$	$7/2_1^-$	$1{\cdot}28 \times 10^{12}$	$8{\cdot}8 \times 10^{11}$	$2{\cdot}16 \times 10^{12}$	18	7·2
$5/2_3^-$	$3/2_1^-$	$1{\cdot}32 \times 10^{12}$		$1{\cdot}32 \times 10^{12}$	11	1
$5/2_3^-$	$5/2_1^-$	$7{\cdot}2 \times 10^9$	$4{\cdot}8 \times 10^9$	12×10^9	0·1	1·6
$5/2_2^-$	$7/2_1^-$	$1{\cdot}2 \times 10^{13}$	$4{\cdot}48 \times 10^{12}$	$164{\cdot}8 \times 10^{11}$	22	8·9
$5/2_2^-$	$9/2_1^-$	$7{\cdot}2 \times 10^{11}$		$7{\cdot}2 \times 10^{11}$	1	1
$9/2_3^-$	$7/2_1^-$	$3{\cdot}36 \times 10^9$	$2{\cdot}24 \times 10^9$	$5{\cdot}6 \times 10^9$	0·003	1
$9/2_3^-$	$5/2_1^-$	$20{\cdot}3 \times 10^{11}$		$20{\cdot}3 \times 10^{11}$	1	4·6
$9/2_3^-$	$9/2_1^-$	985×10^9	$0{\cdot}85 \times 10^9$	$950{\cdot}8 \times 10^9$	0·46	1
$3/2_2^-$	$7/2_1^-$	$1{\cdot}6 \times 10^{10}$		$1{\cdot}6 \times 10^{10}$	0·2	0·35
$3/2_2^-$	$3/2_1^-$	$0{\cdot}84 \times 10^{11}$	$1{\cdot}76 \times 10^9$	$8{\cdot}57 \times 10^{10}$	1	1.18
$3/2_2^-$	$5/2_1^-$	$2{\cdot}46 \times 10^{10}$	$1{\cdot}14 \times 10^9$	$2{\cdot}57 \times 10^{10}$	0·3	0·41
$9/2_2^-$	$7/2_1^-$	$13{\cdot}6 \times 10^{10}$	$1{\cdot}12 \times 10^6$	$13{\cdot}6 \times 10^{10}$	13·6	1·2
$9/2_2^-$	$5/2_1^-$	1×10^{10}		1×10^{10}	1	1

† Experimental branching ratios are calculated from transition intensities where no uncertainty in the measurements has been predicted (Hillis *et al* 1975).

and octupole one phonon vibrational states of ^{150}Nd core with the quasiparticle states mentioned above and diagonalised. Earlier measurements by (*d*, *t*) reaction (Burke *et al* 1973) also reveals the population of some neutron hole states of the isotope. We have compared our results with ^{150}Nd (*d*, *t*) reaction spectrum (Løvhøiden *et al* 1980) up to 1·7 MeV. V_j^2, X_2, X_3 and ε_j are parametrized to get best fit with the experimental energies and spectroscopic factors (Løvhøiden *et al* 1980) (table 1). The energy level diagram is depicted in figure 3.

Three fragments of the $1/2^+$ state at 0·48, 0·81 and 0·98 MeV are detected from experiment whereas we are able to locate six fragments at 0·90, 0·98, 1·05, 1·16, 1·31 and 1·35 MeV with appreciable spectroscopic factors. In case of $3/2^+$ states, only four fragments have been extracted instead of six from experiment. It shows that all the $3/2^+$ states do not possess collective vibrational structures. Three $5/2^-$ states are obtained against two from experimental observation. No fragmentation is found for the $11/2^-$ state. More refined experiments are necessary to search for $3p_{1/2}$, $1h_{9/2}$ and $1i_{13/2}$ states of this isotope as well as to prove the validity of the model. In spite of few limitations, the present model is able to explain the basic fragmented pattern seen through experiment.

4. Conclusion

In view of our theoretical calculation on these three odd-A Nd isotopes, it is necessary to examine the correctness of the parameters employed. First of all the quasiparticle

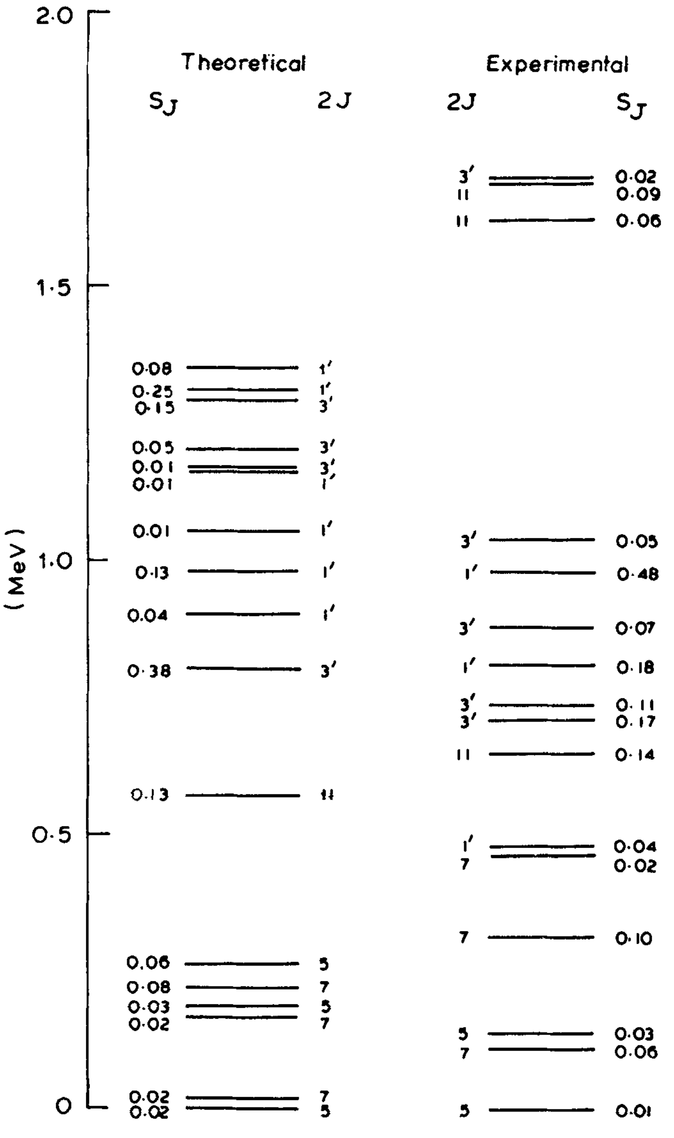

Figure 3. Energy level diagram with spectroscopic factors for various spin states of ^{149}Nd. The dashed numbers (1, 3) indicate positive parity states.

energies employed in the calculation are in close proximity with the centroid energy values calculated from the reaction spectrum within 2 MeV excitation energy region. The low excitation energies of the hole states underlying $N = 82$ neutron core might be due to deformation of the nuclei that can lower the energy gap between major oscillator shells considerably. In view of this physical situation an anharmonic picture of the core vibrator fits well within the framework of the proposed model. The failure to reproduce the basic fragmented pattern in ^{145}Nd from cluster-core model (Dias *et al* 1982;

Dragulescu *et al* 1984) also shows the applicability of the unified model interpretation with pairing interaction incorporated therein. Physical conformation for the adopted V_j^2 and U_j^2 for the three isotopes seems to be judicious as these are estimated from the reaction spectrum and the tabulated values lie in close proximity with the experimental estimates. Better results regarding BE(2) and BM(1) rates are obtained with our model in ^{147}Nd when results based on particle rotor model calculations are compared. Moreover the effect of core polarisation on the shell model energies of the neutron hole and particle states in this transitional region is stressed as these energies are derived from direct comparison with the clean one step transfer reactions. This effect has already been noticed in our work on ^{207}Pb (Mukherjee and Majumdar 1979). Failure to get the splitting regarding the $1h_{11/2}$ and $1i_{13/2}$ states in these three nuclei forbids any conclusion regarding the structure of the states. A qualitative explanation for the low lying and low spin positive parity hole states of these isotopes can be obtained by means of the macroscopic-microscopic Strutinsky method (Brack *et al* 1972) and a comparison with the present theoretical calculation is stressed to compare the validity of the present model.

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