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ENERGY SPECTRA OF THE ^{137}Ba, ^{139}Ce, ^{141}Nd AND ^{143}Sm NUCLEI CALCULATED WITH THE USE OF THE PARTICLE-SURFACE COUPLING STRENGTH DEPENDING ON THE SINGLE NEUTRON-HOLE STATES

By D. Chlebowska

Institute for Nuclear Research, Warsaw*

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Particle-surface coupling strength matrix elements calculated with Woods-Saxon wave functions are used in the study of the energy spectra of the ^{137}Ba, ^{139}Ce, ^{141}Nd and ^{143}Sm nuclei. The comparison with the theory, in which the coupling strength has been treated as a parameter, is made. In both cases the general features of the spectra are similar, although there are some differences, especially in the values of spectroscopic factors. Agreement between calculated nuclear properties and available experimental data is good.

1. Introduction

In papers [1] and [2] the intermediate coupling unified model [3] has been applied to nuclei with one neutron-hole in the closed shell with $N = 82$. In these papers the particle-vibration coupling strength has been treated as a parameter which had a constant value for a given nucleus. For the quadrupole deformation the coupling strength ξ is determined by

$$\xi = k(r)\,(5/2\pi\hbar\omega C_2)^{1/2}$$

where C_2 is the surface stiffness of the core, $k(r)$ is the operator, which is connected with the change of the nuclear potential at the boundary

$$k(r) = -r\frac{\partial V(r)}{\partial r}.$$

Matrix elements of the particle-surface interaction Hamiltonian contain radial matrix elements of the operator $k(r)$.

In the present paper we want to investigate how the energy spectra and wave functions of the nuclei ^{137}Ba, ^{139}Ce, ^{141}Nd and ^{143}Sm will be changed if the Woods-Saxon wave functions matrix elements of $k(r)$ are used instead of k = constant.

* Address: Instytut Badań Jądrowych, Hoża 69, 00-681 Warszawa, Poland.

2. *Calculations and results*

In our calculations the neutron-hole — surface coupling strength ξ is a matrix with elements $\langle lj|\xi(r)|l'j'\rangle$. These matrix elements have been calculated in the paper [4]. The values od $\langle lj|\xi(r)|l'j'\rangle$ used by us are written in Table I.

TABLE I

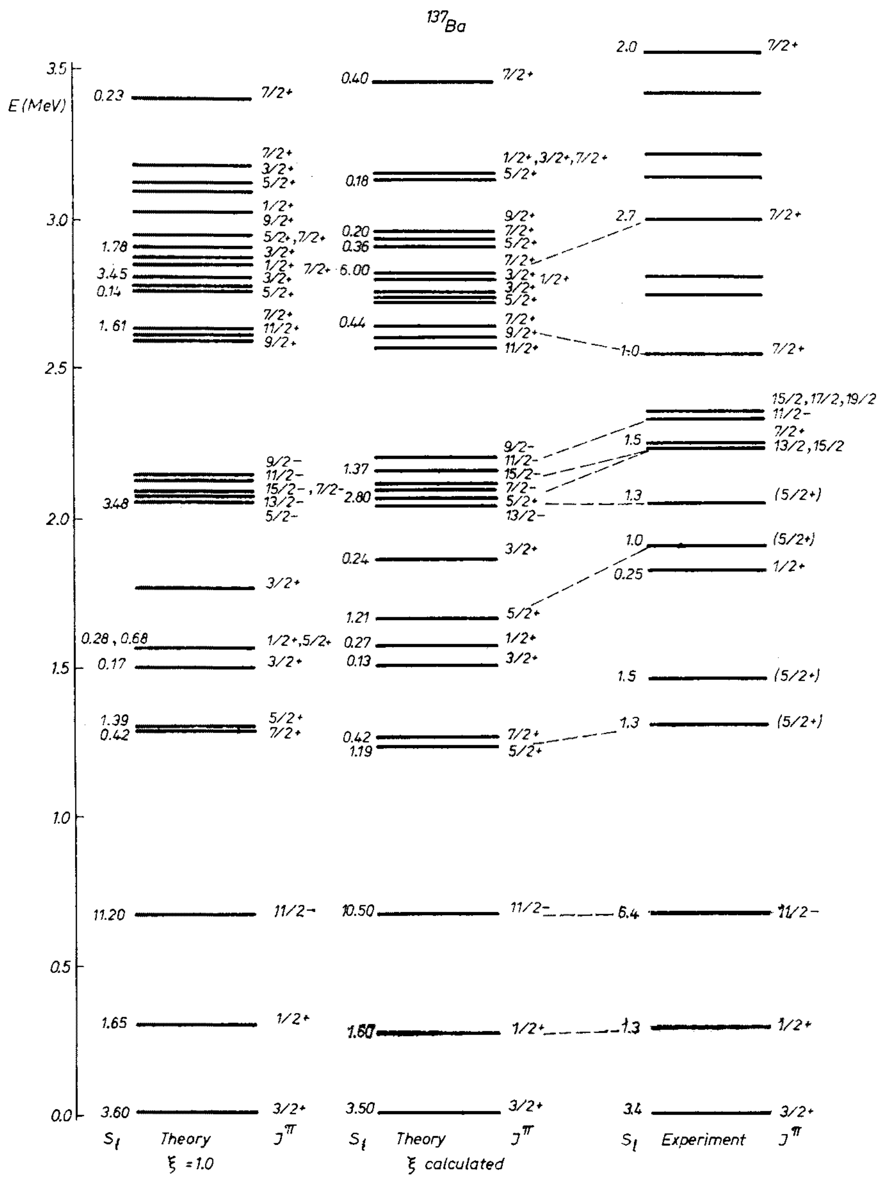
Radial matrix elements $\langle lj|\xi(r)|l'j'\rangle$ used in the calculations

Matrix elements \ Nucleus	^{137}Ba	^{139}Ce	^{141}Nd	^{143}Sm
$\langle d_{3/2}\|\xi(r)\|d_{3/2}\rangle$	1.21	1.05	1.02	0.94
$\langle d_{3/2}\|\xi(r)\|s_{1/2}\rangle$	−1.16	−1.01	−0.98	−0.91
$\langle d_{3/2}\|\xi(r)\|h_{11/2}\rangle$	−1.28	−1.10	−1.09	−1.00
$\langle d_{3/2}\|\xi(r)\|d_{5/2}\rangle$	1.18	1.03	1.00	0.92
$\langle d_{3/2}\|\xi(r)\|g_{7/2}\rangle$	−1.03	−0.89	−0.87	−0.80
$\langle s_{1/2}\|\xi(r)\|s_{1/2}\rangle$	1.16	1.00	0.98	0.91
$\langle s_{1/2}\|\xi(r)\|h_{11/2}\rangle$	1.16	1.00	0.98	0.90
$\langle s_{1/2}\|\xi(r)\|d_{5/2}\rangle$	−1.15	−1.00	−0.98	−0.90
$\langle s_{1/2}\|\xi(r)\|g_{7/2}\rangle$	0.91	0.80	0.78	0.73
$\langle h_{11/2}\|\xi(r)\|h_{11/2}\rangle$	1.48	1.28	1.25	1.15
$\langle h_{11/2}\|\xi(r)\|d_{5/2}\rangle$	−1.24	−1.05	−1.05	−0.97
$\langle h_{11/2}\|\xi(r)\|g_{7/2}\rangle$	1.24	1.07	1.04	0.96
$\langle d_{5/2}\|\xi(r)\|d_{5/2}\rangle$	1.16	1.01	0.99	0.91
$\langle d_{5/2}\|\xi(r)\|g_{7/2}\rangle$	−0.99	−0.86	−0.84	−0.77
$\langle g_{7/2}\|\xi(r)\|g_{7/2}\rangle$	1.05	0.91	0.88	0.81

The results are presented on Figs 1–4, where, for comparison, energy spectra calculated with the constant ξ are also shown. In the last case the best fit has been obtained with $\xi = 1.5$ for ^{139}Ce, ^{141}Nd and ^{143}Sm and with $\xi = 1.0$ for ^{137}Ba [1]. The calculated values of $\langle|\xi(r)|\rangle$ are smaller than 1.5, they equal about 1.0. Moreover, many of the off-diagonal matrix elements of $\xi(r)$ have negative sign.

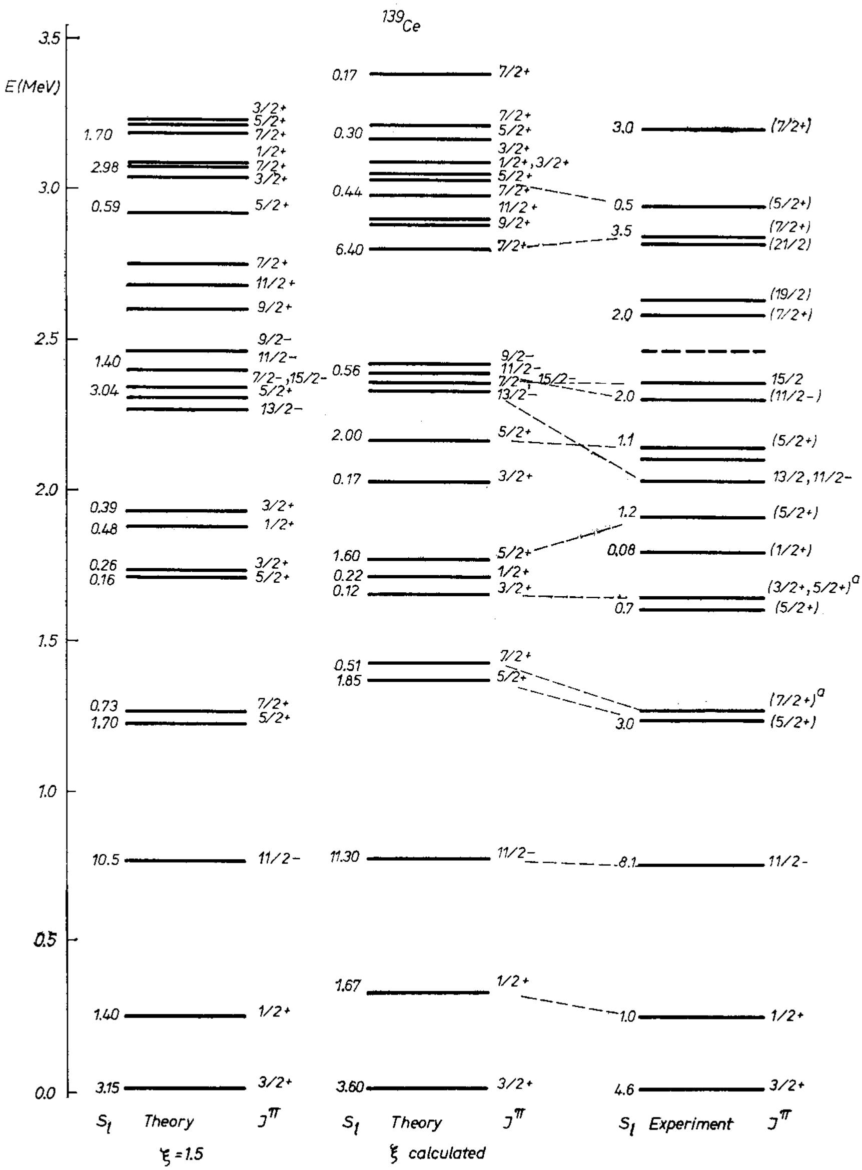
In the calculations the coupling of the neutron-hole in the states $2d_{3/2}$, $3s_{1/2}$, $1h_{11/2}$, $2d_{5/2}$ and $1g_{7/2}$ with harmonic oscillations up to three phonons is taken into account. The phonon energies are assumed to be equal to the energies of the 2^+ levels in the neighbouring $N = 82$ nuclei. For even-parity states single-neutron-hole energies, which have been fitted to the experiment in the paper [1], yield good results also in our calculations. The $1h_{11/2}$ state energies, which give the good position of the first $11/2-$ level, are greater than those obtained for k = constant. The values of the parameters which are used in our calculations are listed in Table II.

As one can see from the Figures 1–4 the general features of the spectra obtained with ξ depending on the single-neutron-hole states and those calculated with ξ constant are similar. In the first case the agreement with experiment seems to be better for $5/2+$ states. For $7/2+$ states the value $\xi \approx 1.0$ is too small. The calculated splitting of the levels in the



137Ba
E (MeV)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
S_l Theory J^π
ξ = 1.0
S_l Theory J^π
ξ calculated
S_l Experiment J^π

Fig. 1



139Ce
E(MeV)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.70
2.98
0.59
1.40
3.04
0.39
0.48
0.26
0.16
0.73
1.70
10.5
1.40
3.15
3/2+
5/2+
7/2+
1/2+
7/2+
3/2+
5/2+
7/2+
11/2+
9/2+
9/2-
11/2-
7/2-,15/2-
5/2+
13/2-
3/2+
1/2+
3/2+
5/2+
7/2+
5/2+
11/2-
1/2+
3/2+
0.17
0.30
0.44
6.40
0.56
2.00
0.17
1.60
0.22
0.12
0.51
1.85
11.30
1.67
3.60
7/2+
7/2+
5/2+
3/2+
1/2+,3/2+
5/2+
7/2+
11/2+
9/2+
7/2+
9/2-
11/2-
7/2-
15/2
13/2-
5/2+
3/2+
5/2+
1/2+
3/2+
7/2+
5/2+
11/2-
1/2+
3/2+
3.0
0.5
3.5
2.0
2.0
1.1
1.2
0.08
0.7
3.0
8.1
1.0
4.6
(7/2+)
(5/2+)
(7/2+)
(21/2)
(19/2)
(7/2+)
15/2
(11/2-)
(5/2+)
13/2,11/2-
(5/2+)
(1/2+)
(3/2+,5/2+)a
(5/2+)
(7/2+)a
(5/2+)
11/2-
1/2+
3/2+
S_l Theory J^π
ξ=1.5
S_l Theory J^π
ξ calculated
S_l Experiment J^π

Fig. 2

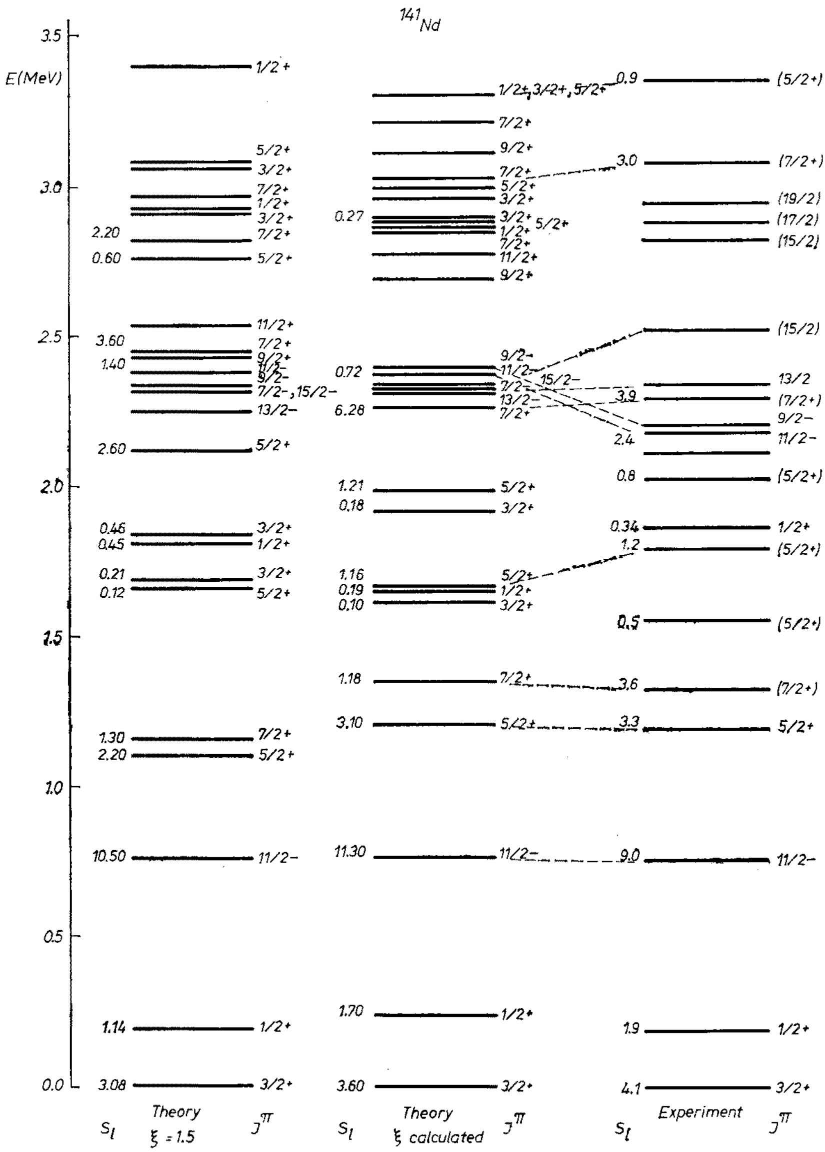


Fig. 3

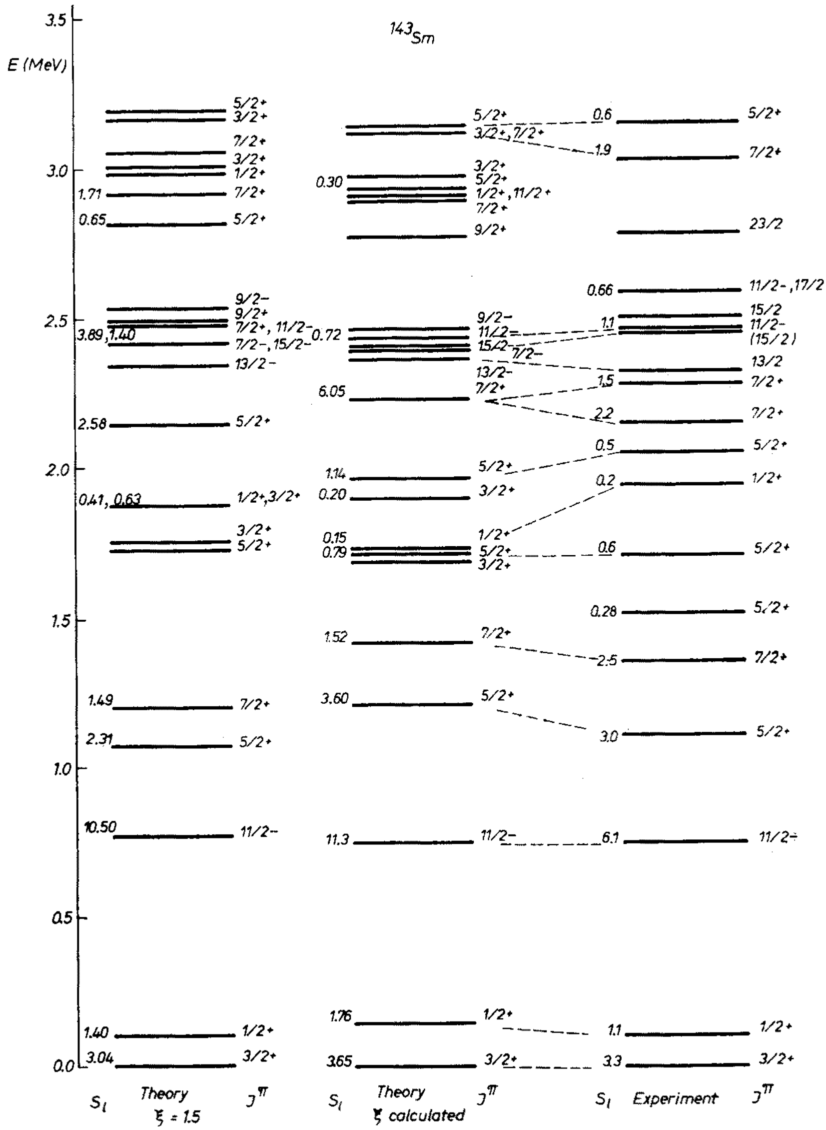


Fig. 4

Figs 1–4. Excited spectra of the ^{137}Ba, ^{139}Ce, ^{141}Nd and ^{143}Sm nuclei calculated with the use of the coupling strength matrix elements $\langle lj|\xi(r)|l'j'\rangle$ are compared with experiment and with results of the calculations using ξ = constant. The experimental data are taken from the papers: [4] (levels with $J \geqslant 11/2$), [5] (levels with $J < 11/2$), and [6] (levels marked by a letter a)

TABLE II

Single-neutron-hole energies, phonon-energies and coupling strengths used in the calculations. For the $1h_{11/2}$ state upper values correspond to the theory using the $\langle lj|\xi(r)|l'j'\rangle$ matrix elements, the lower values are used in the calculations with ξ = constant

Δl_j \ Nucleus	^{137}Ba	^{139}Ce	^{141}Nd	^{143}Sm
$\Delta d_{3/2}$	0.00	0.00	0.00	0.00
$\Delta s_{1/2}$	0.38	0.42	0.32	0.20
$\Delta h_{11/2}$	0.60	0.65	0.65	0.65
	0.54	0.44	0.41	0.39
$\Delta d_{5/2}$	1.70	1.70	1.40	1.35
$\Delta g_{7/2}$	2.60	2.60	2.00	1.95
$\hbar\omega$	1.4360	1.5960	1.5760	1.6590
ξ	1.0	1.5	1.5	1.5

doublets 13/2−, 15/2− is smaller than the experimental value by a factor of about 0.5 in both cases. The position of these doublets is in agreement with experiment.

One can say that the unified model calculations with ξ treated as a parameter and calculations with the estimated $\langle lj|\xi(r)|l'j'\rangle$ matrix elements are applicable to the considered nuclei, however, in the last case theory is more exact and contains smaller number of parameters.

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REFERENCES

[1] K. Heyde, J. Brussard, *Z. Phys.* **259**, 15 (1973).

[2] D. Chlebowska, *Acta Phys. Pol.* **B6**, 641 (1975).

[3] A. Bohr, B. R. Mottelson, *K. Danske, Vidensk. Selsk. Mat. Fys. Medd.* **27**, No 16 (1953).

[4] H. Arnold, H. Ryde, J. Kownacki, J. Ludziejewski, Z. Sujkowski, *Nucl. Phys.* **A236**, 125 (1974); A. Kerek, J. Kownacki, *Nucl. Phys.* **A206**, 245 (1973); J. Ludziejewski, H. Arnold, to be published.

[5] R. K. Jolly, E. Kashy, *Phys. Rev.* **C4**, 887, 1398 (1971).

[6] D. B. Beery, W. H. Kelly, W. C. McHarris, *Phys. Rev.* **188**, 1875 (1969).