сообщения
объединенного
института
ядерных
исследований
дубна

E4 - 13005

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CALCULATION OF THE NEUTRON STRENGTH FUNCTIONS OF ODD SPHERICAL NUCLEI WITHIN THE QUASIPARTICLE-PHONON MODEL

1980

The neutron strength functions are important characteristics of the neutron resonances. As a rule, they are calculated in the framework of the optical model [1], which fails to describe the strength functions at minima. In recent years microscopic models have received the application for the neutron strength function calculations, for instance for the calculations within the shell model approach to nuclear reactions [2].

During the last years many investigations have been performed within the quasiparticle-phonon nuclear model [3] to study the fragmentation of a few quasiparticle components of the wave functions at low, intermediate and high excitation energies [4-6]. The neutron strength functions are well described in the odd deformed [4] and spherical [5] nuclei. The spin dependence of the neutron strength functions in doubly even spherical nuclei has been investigated in ref. [7].

The aim of the present paper is to calculate the s- and p-wave neutron strength functions for a larger number of odd spherical nuclei than in ref. [5]. The modification of our paper is the inclusion of the isovector part of the long-range effective forces into the Hamiltonian, which are very important for the description of the giant resonances and the strength distribution of electromagnetic transitions [8,9].

The model Hamiltonian includes the average field as the Saxon-Woods potential, the pairing interaction and factorized multipole and spin-multipole forces. The multipole and spin-multipole forces generate the phonon states with the relevant values of spins and parity. The majority of Hamiltonian parameters are fixed from the experimental data taken from refs. [6-9]. In our model [3] the quasiparticle-phonon interaction, causing the fragmentation of one-quasiparticle components, which gives the values of the strength functions, is determined by the parameters of the average field and strength constants of the aforesaid interactions. So, we have no free parameters in our calculation in odd nuclei.

The wave functions of the states of odd-N spherical nuclei have the following form:

$$\Psi_\nu (JM) = \{C_J^\nu \alpha^+_{JM} + \sum_{\lambda i j} D_j^{\lambda i} (J\nu)[\alpha^+_{jm} Q^+_{\lambda\mu i}]_{JM}\}\Psi_0 . \qquad (1)$$

Here $\alpha^+(Q^+)$ is the quasiparticle (phonon) creation operator and Ψ_0 is the ground state of the doubly even nucleus. The energies $\eta_{J\nu}$ of the states $\Psi_\nu(JM)$ are defined from the secular equation

$$F(\eta) = \epsilon_J - \eta_{J\nu} - \frac{1}{2}\sum_{\lambda i j} \frac{\Gamma^2(Jj\lambda i)}{\epsilon_j + \omega_{\lambda i} - \eta_{J\nu}} = 0 , \qquad (2)$$

where

$$\Gamma(Jj\lambda i) = \sqrt{\frac{2\lambda+1}{2J+1}} \; \frac{f^{\lambda}_{Jj}\, v^{(\mp)}_{Jj}}{\sqrt{\mathcal{Y}_n(\lambda i)}} ,$$

f^{λ}_{Jj} is the reduced single-particle matrix element of the multipole (or spin-multipole) operator and $v^{(\mp)}_{Jj}$ are the combinations of the Bogolubov transformation coefficients u and v. The detailed description of all the quantities is given in refs. [3,6]. One can prove the following relation for the coefficients C^{ν}_J

$$[C^{\nu}_J]^{-2} = - \frac{\partial F(\eta)}{\partial \eta}\Big|_{\eta=\eta_{J\nu}} \qquad (3)$$

in the case when the neutron with orbital momentum ℓ is absorbed by the target-nucleus with spin I_0 ($I_0 = 0$ in our case), the ℓ -wave neutron strength function is determined by the formula

$$S_{\ell} = \sum_J g(J)\, S^J_{\ell} , \qquad (4)$$

where $g(J) = \frac{2J+1}{2(2I+1)(2\ell+1)}$ is the statistical weight, and S^J_{ℓ} is the value of the ℓ-strength function with a given value of spin J. Within the quasiparticle-phonon model S^J_{ℓ} is expressed through the coefficient[10] C^{ν}_J and is

$$S^J_{\ell} = \frac{\Gamma^{\circ}_{s.p.}}{\Delta E} \sum_{\nu \in \Delta E} |C^{\nu}_J|^2\, u^2_J , \qquad (5)$$

where ΔE is the energy averaging interval and $\Gamma^{\circ}_{s.p.}$ is the reduced single-particle width. To evaluate the reduced single-particle widths for the Saxon-Woods potential, we use the semiempirical formula from ref. [11]

$$\Gamma^{\circ}_{s.p.} = 2kR \frac{h^2}{MR^2\sqrt{E}}(1 + 6{,}7\, d^2) , \qquad (6)$$

where k is the neutron wave number, R is the nuclear radius and d is the diffuseness parameter of the Saxon-Woods potential. For the nuclei under consideration $\Gamma^{\circ}_{s.p.} \sim 50/A^{1/3}$ keV.

To simplify the calculations it is very convenient to introduce the quantity $[C^{\nu}_J]^2$ averaged with the Lorentz weight function

$$S_J(\eta) = \frac{1}{2\pi} \sum_{\nu} (C^{\nu}_J)^2 \frac{\Delta}{(\eta-\eta_{J\nu})^2 + \Delta^2/4} . \qquad (7)$$

By inserting relation (3) into (7) and changing the sum to the integral over the complex plane, one can obtain the explicit form of the function $S_J(\eta)$ (see refs. [3,5]). When

Table 1

s -wave neutron strength functions

Nucleus	B_n, MeV	Ref.	$S_o \times 10^4$	
			Experiment	Calculation
^{55}Cr	6,25	13	1,8±1,0	2,3
^{57}Fe	7,65	14	2,6±0,86	3,0
^{59}Ni	8,999	13	3,1±0,8	3,2
^{61}Ni	7,82	13	2,4±0,6	2,4
^{63}Ni	6,84	13	2,9±0,7	2,5
^{75}Ge	6,5	13	1,3±0,8	3,0
^{93}Zr	6,76	13	1,6±0,6	2,0
^{97}Mo	6,82	13	0,7±0,26	0,83
^{99}Mo	5,93	13	0,7±0,2	0,95
^{117}Sn	6,94	13	0,26±0,05	0,19
^{119}Sn	6,48	13	0,4±0,15	0,15
^{121}Sn	6,18	13	0,08±0,06	0,11
^{123}Sn	5,95	15	0,4±0,25	0,15
^{125}Te	6,48	15	0,7±0,2	0,2
^{127}Te	6,35	15	0,31±0,1	0,12

calculating the strength function S_ℓ^J, one should change $\sum_\nu (C^\nu_J)^2 \to \int_{\Delta E} d\eta S_J(\eta)$. We have performed our calculations with $\Lambda = 0.5$ MeV. The variation of Λ from 0.3 to 1.0 MeV changes our results slightly. Our calculations and those of ref. /12/ show, that the influence of the isovector components on the strength functions is not so important. The introduction of the isovector components results in changing S_ℓ^J -values by 20-30%. Our results for the s- and p-wave neutron strength functions and experimental data /13-17/ are given in tables 1 and 2, respectively. It is seen from tables 1,2 that the calculations describe rather well the experimental data and represent correctly the behaviour of S_ℓ as a function of A. For nuclei with A ~60, 120 the maximum of S_0 and the minimum of S_1 are described simultaneously.

Table 2

p-wave strength functions

Nucleus	B_n, MeV	Ref.	$S_1 \times 10^4$ Experiment	$S_1 \times 10^4$ Calculation
^{55}Cr	6,25	13	0,042±0,024	0,08
^{57}Fe	7,65	14	0,4±0,2	0,07
^{59}Ni	8,999	13	0,04±0,03	0,08
^{63}Ni	6,84	16	0,028±0,013	0,03
^{117}Sn	6,94	15	1,35	0,9
^{121}Sn	6,18	13	1,1±0,4	0,7
^{125}Te	6,58	15	2,0	1,6
^{127}Te	6,35	15	1,64	1,4
^{139}Ba	4,72	17	0,9	1,0
^{143}Nd	6,13	17	1,0±0,4	1,0
^{145}Nd	5,76	17	0,9±0,4	1,3

So, within the quasiparticle-phonon nuclear model one can describe satisfactorily the experimental data for the neutron strength functions in even-even /8/ and odd spherical nuclei, using the same Hamiltonian parameters.

The authors are grateful to Prof. V.G.Soloviev for useful discussions.

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Received by Publishing Department
on December 14 1979.