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NUCLEAR STRUCTURE CALCULATIONS FOR DEFORMED NUCLEI

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ABSTRACT

The generalized Hartree-Fock method is applied to a calculation of equilibrium deformations of Mg^{24} and neighbouring nuclei. A nucleon-nucleon potential of Gaussian shape and Serber exchange character is used. The quadrupole moments obtained agree reasonably with the measured values. The Nilsson potential turns out to be a rather good approximation to the self consistent field.

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We have used the generalized Hartree-Fock method [1] in a study of nuclear properties in the region of strongly deformed light nuclei around Mg^{24}. The method can be described as a variational principle with a Bardeen-Cooper-Schrieffer trial state [2]

$$\Psi = \prod_{\nu > 0} (U_\nu + V_\nu \, b^+_\nu \, b^+_{-\nu}) \, \phi_0 \qquad (1)$$

The index ν labels the single particle states, $-\nu$ refers to the time reversed state and ϕ_0 is the vacuum state. The creation operators b^+_ν are obtained from an original set of basis operators a^+_j by a unitary linear transformation.

$$b^+_\nu = \sum_j d^j_\nu \, a^+_j \qquad (2)$$

The variations of V_ν, U_ν and d^j_ν must be chosen such that Ψ is normalized, transformation (2) is unitary and the average particle number is fixed. The nuclei were supposed to be axially symmetric. The variational equations were solved numerically neglecting the influence of the "pairing potential" [3] on the selfconsistent field. Oscillator wave functions served as a basic set $a^+_j \, \phi_0$. All single particle states up to the principal quantum number $N = 3$ were taken into account.

A nucleon-nucleon force of Gaussian shape and Serber exchange character was used and a phenomenological spin-orbit splitting was introduced. The frequency ω of the oscillator was chosen such as to give approximately the correct nuclear radius. The effect of the short range repulsive part of the nuclear force was simulated in one case by a repulsive Gaussian force. The numerical values of the parameters are given in Table I, and the numerical results are compared with experimental data in Table II. The quadrupole moments come out rather close to the experimental values and the break from prolate to oblate groundstate deformations above Mg^{24} is obtained. The contribution of the deformed O^{16}-core to the total quadrupole moments is between 10 and 15%. Agreement could be most probably improved by some changes of the force parameters. The calculated decoupling parameters of the $K = 1/2$ bands agree reasonably well with experimental values.

In comparing the energy levels of the self consistent field with those of a Nilsson potential [4] one finds a remarkable similarity. Some significant differences, however, show up in the single particle wave functions. As an example, when going from Al^{25} to Al^{27} and thus changing the neutron number by two, we find that the single particle functions of the protons change more than can be explained by a change in deformation, particularly since the quadrupole moment remains almost unchanged. Further there is an appreciable diffuseness of the Fermi surface for positive parity states although the effect of pairing is generally smaller than in the case of heavy nuclei.

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Table I. Force parameters and oscillator constant $\alpha = \frac{m\omega}{\hbar}$.

		Case A	Case B	Case C
Range	(F)	1.70	1.70	1.70
V_{SE}	(MeV)	-33.5	-33.5	-33.5
V_{TE}	(MeV)	-48.6	-48.6	-48.6
α	(F^{-2})	0.346	0.30	0.30
Repulsive Core				
Range	(F)	-	-	0.80
V_{SE}	(MeV)	0.0	0.0	33.5
V_{TE}	(MeV)	0.0	0.0	48.6

Table II. Intrinsic quadrupole moments Q_o (Barns) and decoupling factors a of K = 1/2 rotational bands, calculated[a] and experimental.

Element	Q_o (calc.)			Q_o (Exp.)
	Case A	Case B	Case C	
Na^{23}	0.290	0.326	0.330	0.50
Mg^{24}	0.316	0.352	0.356	0.58
Mg^{25}	0.316	0.356	0.356	
Mg^{26}			0.343	
Al^{25}	0.257	0.285	0.289	.43
Al^{27}			0.277	.42
S^{32}	-0.271		-0.305	
S^{33}	-0.271		-0.305	-0.33

Element	Nilsson State	a (Calc.)			a (Exp.)
		Case A	Case B	Case C	
Mg^{25}	$1/2^+$ [211]	0.286	0.421	0.810	-0.20
	$1/2^+$ [200]	-0.259	-0.592	-1.07	-0.42
	$1/2^-$ [330]	-2.354	-2.623	-2.665	-3.50
Al^{25}	$1/2^+$ [211]	0.286	0.421	0.810	-0.02
	$1/2^+$ [200]	-0.259	-0.592	-1.07	-0.56
	$1/2^-$ [330]	-2.354	-2.623	-2.665	-3.20

a) The calculated values for odd mass nuclei are based on the quasi-particle picture.