

SHELL-MODEL HAMILTONIAN AND PARTICLE-VIBRATION COUPLING

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It is an important problem in nuclear structure how protons and neutrons correlate with each other. One of the examples for this problem is the study of the structure of the $N = 30$ nuclei with $Z = 20-28$ which have active protons and neutrons outside the ^{48}Ca core. Shell-model calculations (ref. [1]) for these nuclei have been carried out within the proton-neutron configurations $(1f_{7/2})_p^{Z-20} \times (2p_{3/2}, 2p_{1/2}, 1f_{5/2})_n^2$.

The Hamiltonian is written as

$$H = H_{s.p.} + V_{pp} + V_{nn} + V_{pn} \quad (1)$$

Single particle energies $H_{s.p.}$ and the proton-proton interactions V_{pp} are taken from the observed energies in the nucleus ^{40}Ca and the $N = 28$ nuclei, respectively. The matrix elements of the neutron-neutron interactions V_{nn} have been determined by the shell model calculation for Ni isotopes (ref. [2]).

The proton-neutron (p-n) interactions are investigated in detail in ref. [3] and their matrix elements are determined by a least-square-fit to the low-lying energy levels of $N = 29$ isotones.

The results of ^{55}Mn are shown in fig. 1. The experimental spectra (fig. 1a) are well reproduced by the shell-model calculation (fig. 1b). Agreement between the calculated energy spectra and the observed ones is also satisfactory for the other nuclei. The resultant wave functions show the breakdown of the pairing scheme and strong proton-neutron correlation.

In order to know the property of the proton-neutron

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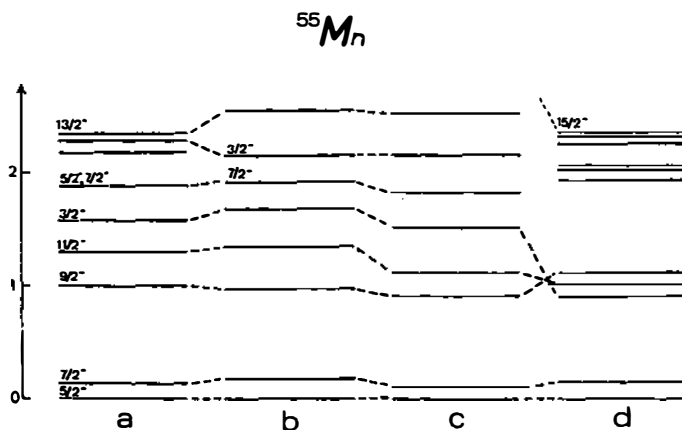


Fig.1. Energy spectra of ^{55}Mn .
 a) experiment, b) shell-model calculation (ref. [1]), c) shell-model calculation (truncated), d) Alaga model (ref. [4]).

correlations, we try to reproduce the matrix element of the p-n interactions adopted here by a simple force. It is noticeable that the gross feature of these matrix elements is reproduced by the monopole plus quadrupole force. Since the monopole part of the p-n interactions renormalizes the single-particle energies, we can write the Hamiltonian as

$$H = H_{s.p.}' + V_{pp} + V_{nn} + k(C_p \cdot C_n) \quad (2)$$

where $H_{s.p.}'$ is the modified single-particle Hamiltonian. The matrix elements of the quadrupole part in the p-n interaction, $(C_p \cdot C_n)$ can be written as follows

$$\begin{aligned} \langle J_p J_n | (C_p \cdot C_n) | J_p J_n \rangle &= W(J J_n J_p^2; J_p J_n) \cdot \\ &\cdot \langle J_p || C_p || J_p \rangle \langle J_n || C_n || J_n \rangle \end{aligned} \quad (3)$$

From this equation we can learn which states are strongly coupled by the p-n interactions. In the $(p_{3/2}, p_{1/2}, f_{5/2})_n^2$ configuration, the quadrupole matrix elements among the 0_1^+ , 2_1^+ and 4_1^+ states are quite large. Then a new truncation method can be introduced. We take only three states in the neutron system, i.e. 0_1^+ , 2_1^+ and 4_1^+ , instead of the exact shell model calculations mentioned above. The result of this truncated calculations is shown in fig. 1c. Agreement between the exact shell model (fig. 1b) and the truncated shell model (fig. 1c) is quite satisfactory.

This truncation method, which is based on the large matrix elements of the quadrupole operator, will be applicable to other nuclei with more complicated configurations.

Finally, we can mention the relation between the shell model and the particle-vibration coupling model (Alaga model).

It is easy to show that the latter model corresponds to a special case of the truncated shell model, where we can create further the 0_2^+ and 2_2^+ states in the proton or neutron system which have large quadrupole matrix elements to the 2_1^+ state. As far as the nucleus ^{55}Mn is concerned, the neutron system does not seem to be a vibrator core, because there is discrepancy between the spectra of the truncated shell model (fig. 1c) and of the particle-vibration coupling model in ref. [4] (fig. 1d).

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