Empirical Hamiltonians for sd Shell Model Nuclei

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The so-called realistic interactions for shell-model calculations, as typified by the work of Kuo and Brown, have been shown to be quite successful in predicting the properties of nuclei 3, 4, and 5 nucleons removed from shell closures. However, for nuclei composed of even more active particles, serious failures became evident, even though some features remain well accounted for. The failure of these interactions, when subjected to the rigorous test of predicting a many-body system in which the guidance of the single-particle spectrum is submerged, can be traced back, via a careful examination, to properties of the few particle systems. The central fault seems to lie in an over-estimation of the center-of-gravity strength of the attraction between different orbits. An early attempt to empirically rectify the deficiencies of the Kuo interaction for the sd-shell, described briefly and utilized in Preedom and Wildenthal's article on A=22, has proven to be a rather spectacular success under the study by the Glasgow group of A=23-26 nuclei.

We have been engaged this last year in attempting to expand and put into a more coherent form empirical interactions for the sd-shell nuclei. At present, two Hamiltonians are nearing completion, one normalized for A=18-26 and one for A=32-40. Attempts to obtain a single Hamiltonian for the entire shell have so far been unsuccessful.

The $f_{7/2}$-$d_{3/2}$ Model for the A=35-45 Region

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We are developing a schematic model to interpret the high-spin states observed in the vicinity of ^{40}Ca. The model space encompasses $f_{7/2}$-$d_{3/2}$ configurations which include up to 4 holes in $d_{3/2}$ for positive-parity states and up to 5 holes for negative parity states. A modification of Schiffer's $f_{7/2}$-$d_{3/2}$, $d^2_{3/2}$ and $f^2_{7/2}$ interactions is used as a starting Hamiltonian. Adjustments to the matrix elements are then made to improve the agreement of the calculated multiparticle spectra with experiment. About 130 levels in the A=34-42 region are reproduced with an rms deviation of ~.5 MeV.

Shell Model Calculations for the fp Shell Nuclei

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Shell Model Calculations have been undertaken for $^{57-64}Ni$, $^{58-60}Cu$ and ^{60}Zn with the Modified Surface Delta Interaction (MSDI4) and an effective interaction (EFI4) obtained by a least square fitting procedure. With the doubly closed ^{56}Ni nucleus acting as an inert core, four active orbits $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$ and $1g_{9/2}$ were considered with the restriction that no more than 2 nucleons (coupled to T=1) were allowed to occupy the $g_{9/2}$ orbit. The principle aim is to examine the effects caused by the inclusion of the $g_{9/2}$ orbit. The two-body matrix elements of the effective interaction were obtained from an iterative search with the use of a least-square searching program.[1] Twelve ground-state binding energies and 90 level spacings were included in the search. There are five free parameters used in the MSDI4 case, which are the four strength parameters A_T and B_T of the modified surface delta interaction and the single particle energy of the $g_{9/2}$ orbit. The single particle energies for the $2p_{3/2}$, $1f_{5/2}$ and $2p_{1/2}$ orbits were taken from the experimental spectrum of ^{57}Ni. This calculation gave at best no better a fit to the experimental energy spectra than was obtained in the calculation (MSDI3) for the Ni isotopes of Glaudemans, et al.[2] in which the MSDI interaction was also used but only 3 active orbits, $2p_{3/2}$ $1f_{5/2}$ $2p_{1/2}$, were taken into account. The contribution of $g_{9/2}$ orbit affected mainly the ground-state wave-function and gave rise to a larger gap between the ground state and the first excited levels.

The MSDI4 two-body matrix elements were then used as a starting point for an iterative search where 17 linear combinations of two-body matrix elements, as well as the single particle energy of the $g_{9/2}$ orbit were adjusted so as to obtain a least square fit to the experimental energies. A general improvement in the agreement to the experimental spectra was observed, in particular for the level ordering. In Figure 1, the level schemes obtained for the ^{60}Ni and ^{60}Cu nuclei in the present MSDI4 and EFI4 calculations were compared to the experimental data and to other predictions.[2,3] For a further test of the wave functions, calculations of the single nucleon and two nucleon spectroscopic factors has been made and will be compared with the experimental data.

REFERENCES

1. Program written by W. Chung and B. H. Wildenthal.

2. P.W.M. Glaudemans, et al., Nucl. Phys. A198, 609(1972).

3. J. E. Koops preliminary report on a shell-model calculation for Cu isotopes.