The sd shell revisited

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We consider the background of the universal model-independent interaction for the sd-shell, called USD, and the progress for determining a new interaction by the inclusion of a more complete set of experimental data, in particular the new data for neutron-rich nuclei that has accumulated over the last 20 years.

In 1983 Hobson Wildenthal obtained a universal model-independent two-body interaction USD for the 0s1d shell by fitting single-particle energies (SPE) and two-body matrix elements (TBME) to 447 energies in the sd-shell. The rms deviation for the data was about 150 keV. The USD hamiltonian is defined by a set of 63 numbers given for the sd-shell two-body matrix elements (TBME) and three numbers for the $0d_{5/2}, 0d_{3/2}$ and $1s_{1/2}$ single-particle energies (SPE) given in Table 1 in the paper [1] by Hobson Wildenthal. Since 1983 the USD hamiltonian has been the standard interaction for the sd-shell and has been used in several hundred papers for the interpretation of spectroscopic properties of the nuclei from A=18 to A=38.

Today there is still a motivation for determining effective interactions derived from energy spectra. Although the techniques for calculating an effective interaction from more fundamental principles, such as the renormalized G-matrix, became more quantitative over the years (starting with Kuo-Brown), questions arose concerning the convergence of the perturbation series [2], and in practice the application of the renormalized G matrix to many-particle sd-shell spectra often gave rather poor results for energy levels [3].

Because of the increase in data over last two decades, in particular for nuclei further from stability, and computational advances, we have started a program to repeat the procedure for a more extensive data set (about 750 levels). The first progress we have made is to include the updated set of ground-state binding energies plus some excited states in the neutron-rich oxygen, fluorine and neon isotopes.

The data Wildenthal considered for the middle of the shell was limited by computational speed. For example, in 1983 it took about a day to calculate the 0^+ state of ^{28}Si and the two-body transition density that is required in the fit. Today the computational effort is trivial - it is possible to obtain a complete set of energy levels for all sd-shell nuclei (about 2000 levels) in a few hours and it takes about 12 hours to generate the two-body transition densities for all 750 levels in the fit.

After four iterations we obtain an rms deviation of approximately 150 keV by varying 30 linear combinations of parameters, with the Bonn-A potential providing the other 36 linear combinations that were not varied. This 30-parameter hamiltonian is called USD-05A. We performed further iterations by varying 56 linear combinations of parameters until convergence, giving an rms deviation of 130 keV. The 56-parameter hamiltonian is called USD-05B. The new interactions are very similar to USD, but give a significant improvement for the neutron-rich sd-shell nuclei with changes of up to 1.5 MeV in the binding energies. The complete set of comparisons of energy levels for USD-05A and USD-05B can be found on the web [4].

We are engaged in systematically evaluating the wave functions obtained with the new USD interactions by applying them to many spectroscopic data; spectroscopic factors, beta decay, electromagnetic transitions and moments, neutron and proton knockout, electron scattering and cross-sections for reactions such as those involved in the r-process of astrophysics.

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