The effect of the tensor force on the predicted shell closures in superheavy nuclei

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Introduction

One of the current key questions in the study of nuclear structure at the extremes is related to shell stabilisation in the region of high mass and charge - the superheavy elements. The possible existence and location of the 'island of stability' has been a driving force behind experimental and theoretical efforts for several years[1].

The emergence of a region of long-lived elements beyond the actinides has been predicted since the earliest nuclear models, however, there are discrepancies between the different calculations as to the possible location of the shell gaps in the superheavy region[2]. A current popular topic, related to the effective nucleon-nucleon interaction employed within self-consistent mean-field models, is the role of the tensor interaction on the single-particle structure in nuclei at the limits of stability[3]. The influence of the tensor component on the predictions for the superheavy elements is investigated within the framework of the spherical Skyrme Hartree-Fock (SHF) + BCS model.

The tensor component in SHF models

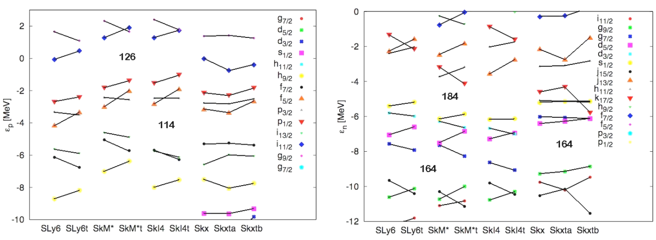
The tensor force is responsible for inducing strong correlations between single-nucleon orbitals with different isospin, which result in a contribution to the binding energy of a system and the spin-orbit splitting of single-particle states. In the SHF approach, the tensor component of the Skyrme effective interaction is written in terms of the coupling strength parameters, U & T:

$$v_t = \frac{T}{2}\left(\left[(\sigma_1\cdot k')(\sigma_2\cdot k') - \frac{1}{3}k'^2(\sigma_1\cdot\sigma_2)\right]\delta(r_1-r_2) + \left[(\sigma_1\cdot k)(\sigma_2\cdot k) - \frac{1}{3}(\sigma_1\cdot\sigma_2)k^2\right]\delta(r_1-r_2)\right)$$
$$+U\left((\sigma_1\cdot k')\delta(r_1-r_2)(\sigma_2\cdot k) - \frac{1}{3}(\sigma_1\cdot\sigma_2)\left[k'\delta(r_1-r_2)k\right]\right)$$

This component has usually been neglected in the fitting process of modern Skyrme parameter sets. However, there have been recent attempts to include it either by refitting one of the existing forces[4] or by adding the tensor term to the existing parameter sets with optimised values for the coupling strengths[5].

Shell structure of ^{298}114

The single-particle structure of the prospective doubly magic nucleus ^{298}114 has been studied for a selection of Skyrme parameterisations both with and without the tensor component.

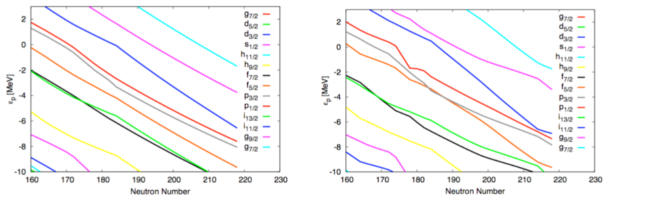


Calculated single-particle spectra for ^{298}114 with mean-field forces as indicated

Inclusion of the tensor term with realistic coupling strength parameters consistently leads to an increased spin-orbit splitting between the proton $2f_{5/2}$ and $2f_{7/2}$ partners, opening the Z=114 shell gap. The Z=126 and N=184 gaps remain major shell closures for all but the Skx series, which predict a shell closure at N=164.

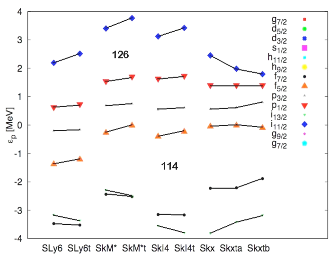
Evolution of the Z=114 & 126 shells

The evolution of single-particle structure across the Z=114 isotopes has been examined. Calculations predict a significant closing of the Z=126 proton gap as a function of increasing neutron number after inclusion of the tensor term, whereas the Z=114 shell gap remains stable over a large range of isotopes.



Evolution of single-proton levels across the Z=114 isotopes for the SLy6 Skyrme force without (left) and with (right) the tensor component

Calculations for the nucleus ^{310}126 reveals further evidence for a Z=114 shell closure. The Z=126 gap is closed in this case, where the inclusion of the tensor term again increases the splitting of the two 2f partners for all Skyrme forces. The single-neutron levels remain unchanged from the structure in ^{298}114.



Single-proton levels in ^{310}126 for the Skyrme forces indicated

Outlook

The tensor component of the Skyrme effective interaction influences the single-particle structure of nuclei in the superheavy region. Further efforts are required to refit the Skyrme parameter sets including this component, where emphasis on the reproduction of the properties of established superheavy nuclei will allow more reliable predictions as experimental efforts approach the island of stability.

References

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