Influence of Non-central force on exotic Cu isotopes

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Introduction

The Shell Model is one of the theoretical approach for the microscopic description of nuclear structure. The model assumes a spherical mean field in which nucleon moves independently from the others nucleons.The influence of two body interactions between neutron and proton is playing a major role in effective single particle energies(ESPE's) of proton or neutron and it has been observed that the energies of the nucleon orbits the "Single particle state" shifts as nuclei are further from region of stability.The gaps between orbits becomes larger or smaller in neutron deficient or neutron-rich nuclei depending on the interactions of the nucleons present in the orbits. It has been reported that the characteristic central and tensor proton-neutron interactions mainly shift the neutron and proton spherical single particle orbitals and develop pronounced energy gap between two orbitals.

In this paper, we intend to investigate the tensor force influence on closed shell Cu isotopes because the Cu nucleus is situated around the β stability, towards very neutron-rich systems and the Cu nucleus can be described by an inert core of Ni(A=56) with one extra proton (particle) and a number of valence neutrons outside the core,i.e.,Closed Shell+1 configuration.The shift of the proton ESPE's orbit by the mean field generated by neutron added to an inert core can be addressed by monopole part of the hamiltonian.Through monopole hamiltonian, to see the tensor force influence over shell evolution,we explicitly separated the effective interaction "JUN45" into individual components by spin-tensor decomposition technique and observed the contribution of each components separately in proton ESPE's as a function of neutron.

Theoretical framework

In the n-p formalism, the monopole hamiltonian can be expressed in terms of neutron and proton number operators

$$H^{np}_{mon} = \sum_{jj'}^{ll'} \epsilon^l_j n^l_j + \frac{\sum^{ll'}_{jj'} V^{ll'}_{jj'} n^l_j (n^{l'}_{j'} - \delta_{jj'}\delta_{ll'})}{(1+\delta_{jj'}\delta_{ll'})} \tag{1}$$

where $V^{ll'}_{jj'}$ represent angular-momentum averaged TBMEs, or centroids of the interaction, l, l' is denoting for neutron and proton and j, j' their angular momentum respectively.

ESPE's can be derived from the monopole hamiltonian as

$$\begin{aligned}\epsilon'^A_{j'} = \epsilon_{j'} + \sum_J (n^\nu_j)[\frac{(n^\nu_j - 1)}{2}(V^{\nu\nu}_{jj}(A) - \\ V^{\nu\nu}_{jj}(A-1)) + V^{\nu\pi}_{jj'}(A)]\end{aligned} \tag{2}$$

where $\epsilon_{j'}$ is proton bare single particle energy, ν and π represent the neutron and proton respectively.

Two-nucleon interaction can be expanded using a decomposition as a sum of scalar, vector and rank-2 spherical tensor[2]

$$V_{LS}(1,2) = \sum_{k=0}^{2} Q^k.S^k = \sum_{k=0}^{2} V^k_{LS} \tag{3}$$

Where $k = 0, 1, 2$ represents central,spin-orbit and tensor components of the effective interaction respectively.

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Result and Discussion

As in fig.1(a), it can be seen in the region N >40 monopole energy shift is towards more negative of ESPE's and in case of $f_{5/2}$ slope is more steeper than slope of $p_{3/2}$ and it becomes lower than $p_{3/2}$ orbit at N>48.The monopole energy shift of the proton orbit $p_{3/2}$ in the region N=40 to N=50 is mainly because of the central components of effective interaction shown in fig.1(b), whereas for proton orbits($f_{5/2}, p_{1/2}, g_{9/2}$) non-central components are responsible for monopole energy shifts.

The ESPE's of the proton $f_{5/2}$ orbit comes down rapidly relative to the $p_{3/2}$ orbit as the filling of neutron start in $g_{9/2}$ orbit for N>40,this is because of the monopole interaction between proton in $p_{3/2}$ and neutron in $g_{9/2}$ is repulsive whereas the interaction between proton in $f_{5/2}$ and neutron in $g_{9/2}$ is attractive. Hence due to the tensor force proton $p_{3/2}$ goes up while $f_{5/2}$ goes down, which is well matched with the predicted ground state $5/2^-$ from systematic study of Cu(A=79)[3],shown in fig.2.

To illustrate the role of tensor force in variation of shell gap, we calculated shell gap between the proton $p_{3/2}$ and $f_{5/2}$ orbitals at N=40 and N=50.It has been found that the variation in the shell gap between the proton $p_{3/2}$ and $f_{5/2}$ orbitals from neutron number N=40 to N=50 is a joint effect of the spin-orbit and tensor component of the effective interaction and very small change is found due to the central components of effective interaction.

Summary

Analysis of monopole energy shift of proton ESPE's orbit and change in shell gap in the region N=40 to N=50,obtained with a rigorous spin-tensor decomposition of the TBMEs, indicate an important role played by the non-central components.

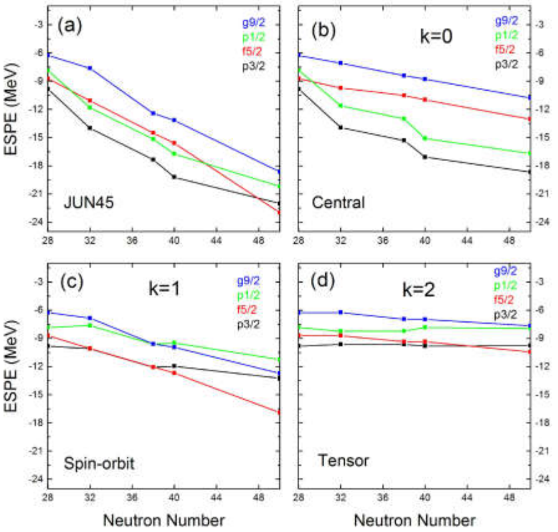

FIG. 1: Proton ESPE's as a function of neutron number due to the individual components of effective interaction.

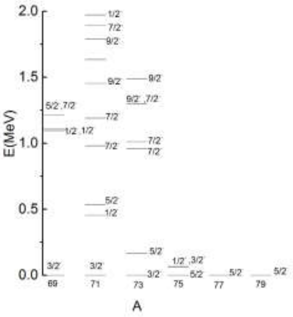

FIG. 2: Experimental low- lying states of Cu isotopes(A=69-79).

References

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