Large-basis shell model calculations of odd-A 63-73Ni isotopes

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الخلاصه

أجريت حسابات أنموذج القشرة بنطاق واسع لنظائر النوى $^{63-73}$Ni الفردية العدد الكتلي والواقعه في منطقة القشرة $f_{5/2}\,pg_{9/2}$ تم حساب مستويات الطاقة ذات التماثل الموجب والسالب وصولاً الى J=15/2 بأستخدام برنامج نموذج القشرة Nushellx@msu عن طريق توظيف التفاعلات المؤثرة jun 45 و jj44b. أجريت مقارنة بين الحسابات النظرية مع البيانات العملية المتوفرة حديثاً. تم الحصول على تطابق مقبول بين البيانات العملية والنتائج النظرية للنوى قيد الدراسه.

الكلمات المفتاحية

أنموذج القشرة، مستويات الطاقة، نيوشيل أكس.

Abstract

Large-scale shell model calculations for neutron-rich odd-A $^{63-73}$Ni isotopes have been performed in the lower $f_{5/2}\,pg_{9/2}$-shell region. The energy levels for positive and negative parity states up to J=15/2 are calculated by using the shell model code Nushellx@msu by employing the effective interactions jun 45 and jj44b. The theoretical calculations are compared with the most recent available experimental data. Reasonable agreement is obtained between the theoretical values and the experimental data for the selected isotopes under study.

Keywords

Shell model, energy levels, Nushellx.

1. Introduction

The shell model [1] has been used for many years to describe the structure of nuclei, especially those that are fairly light or moderately near closed shells. With the steady improvement of computers, the size of the model spaces that can be accommodated has grown, expanding the region of nuclei that can be treated. Neutron-rich nuclei in the A>>60 mass region have been the subject of many recent experimental and theoretical investigations [2].

Recently shell model with large-basis have been performed to study the energy levels and reduced transition probabilities ($B(E2^{+}_{1};0 \rightarrow 2^{+}_{1}$ for even-even $^{66-76}$Ni isotopes by F. A. Majeed *et al*. [3]. Their results show reasonable agreement with the experimental data.

J. Diriken *et al*. [4] have studied in the nearby ^{67}Ni nucleus, -by performing *a* (*d*, *p*) -experiment in inverse kinematics employing a post-accelerated radioactive ion beam (RIB) at the REX-ISOLDE facility. The experiment was performed at energy of 2. 95 MeV/u using a combination of the T-REX particle detectors, the Miniball γ-detection array and a newly-developed delayed-correlation technique as to investigate μs-isomers. A comparison with extended shell model calculations and equivalent (^{3}*He*, *d*) studies in the region around ^{90}Zr highlights similarities for the strength of the negative-parity pf and positive-parity $g_{9/2}$ state.

The aim of the present work is to employ shell model calculations with large basis without imposing any restrictions, to study the low-lying energy levels of odd-A $^{63-73}$Ni nuclei. The calculations will be performed by using the shell model code Nushellx@msu [5] by employing the jun 45 [6] and jj44b [7] effective interactions, to test the ability of the present effective interactions to reproduce the experiment in this mass region.

2. Shell model calculations

Large-scale shell model calculations have been performed for neutron-rich odd-A $^{63-73}$Ni isotopes lies in the $f_{5/2}pg_{9/2}$ shell region. The calculations have been performed with the interactions jun 45 [6] and jj44b [7]. The jun 45 interaction is based on Bonn-C potential, the single-particle energies and two-body matrix elements was modified empirically so as to fit 400 experimental data out of 69 nuclei with A=63-69. In the fitting of jun 45 interaction the experimental data are taken around N=50. The jj44b interaction was obtained from a fit to about 600 binding energies and excitation energies with 30 linear combinations of the good J−T two-body matrix elements. For jj44b the energy data for the fit taken from nuclei with Z=28−30 and N=48−50. The single-particle energies for the $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$ and $1g_{9/2}$ single-particle orbits employed in conjunction with the jun 45 interaction are -9. 8280, -8. 7087, -7. 8388, and -6. 2617 MeV respectively. In the case of the jj44b interaction they are -9. 6566, -9. 2859, -8. 2695, and -5. 8944 MeV, respectively. The core is ^{56}Ni, i. e. N=Z=28, and the calculations are performed in this valence space without truncation. The calculations have been performed using the shell-model code Nushellx@msu [5] on desktop computer dell precision workstation T7500 with xenon processor, cpu 2. 4 Hz, 4-cores, 84GB and 2TB hard disk.

3. Results and discussion

Fig.(1) presents the comparison of our theoretical work using jun 45 and jj44b effective interactions for positive and negative parity states for ^{63}Ni isotope. From this Fig. we noticed that jun 45 effective interaction correctly reproduce the ground-state spin of $1/2^-$. The jj44b interaction, however, fails to correctly reproduce the ground-state spin of $1/2^-$, although the three lowest-lying states of spin and parity $3/2^-$, $5/2^-$, and $1/2^-$ are calculated to lie within a range of only 110 keV, reflecting the close proximity of the neutron single-particle orbitals $2p_{3/2}$, $1f_{5/2}$, and $2p_{1/2}$ in the ^{63}Ni nucleus.

In general, the theoretical values are in good global agreement with the experimental data for both interactions. The spins $9/2^+$, $7/2^-$, $9/2^-$, $13/2^+$, $11/2^+$, and $7/2^+$ experimentally unconfirmed values at 1.291 MeV, 1.451 MeV, 1.451 MeV, 2.183 MeV, 2.183 MeV, and 2.573 MeV, respectively. Jun 45 predict these states at 1.258 MeV, 1.415 MeV, 1.474 MeV, 2.751 MeV, 2.849 MeV, and 2.559 MeV, respectively. The effective interaction jj44b predict these spins at 1.410 MeV, 1.261 MeV, 1.789 MeV, 2.875 MeV, 2.767 MeV and 2.469 MeV, respectively. Spins at $15/2^+$, $13/2^-$ and $15/2^-$ have been predicted by both jun 45 and jj44b effective interactions which have not been assigned experimentally.

The calculated low-lying energy levels are shown in Fig.(2) for ^{65}Ni isotope. The ground-state spin of $5/2^-$ could not be reproduced with jun 45 and jj44b effective interactions. The jun 45 effective interaction is closer to the experimental data and able to reproduce the correct order of the low lying states. The J^π values of $9/2^-$, $7/2^-$, $11/2^+$, $13/2^+$ and $15/2^+$ are not confirmed experimentally, jun 45 predict the values for these spin at 1.844 MeV, 1.287 MeV,

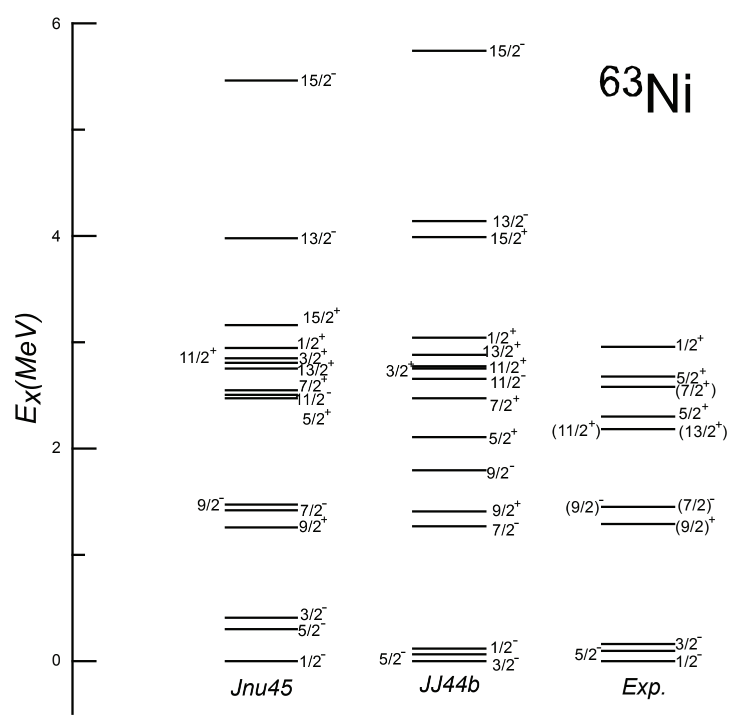

Fig.(1): Comparison of calculated and experimental low-lying spectra for ^{63}Ni isotope with jun 45 and jj44b effective interactions.

2.99 MeV and 2.841 MeV, respectively, while jj44b predict these states at 2.102 MeV, 1.610 MeV, 2.357 MeV, 2.351 MeV and 3.545 MeV respectively. The spin $7/2^-$ have been predicted lower than $9/2^+$ using jj44b effective interaction which is in reverse order compared with the experimental values, this crossover behavior might be attributed to the shape change from vibrational to rotational collectivity as the number of neutrons or protons increases from shell closure towards midshell. In general the agreement between theoretical calculations and the experimental data from jun 45 and jj44b is reasonable for low-lying levels, as seen in Fig.(2).

Fig.(3) displays the comparison between our calculations with the experimental data for ^{67}Ni isotope. The two interactions used in the present work are able to reproduce the ground state spin $1/2^-$. Both effective interactions are able to reproduce the correct ordering of the low-lying spins $5/2^-$ and $9/2^+$ and the predicated values with jj44b effective interactions are more in agreement with the experimental data than jun 45.

In Fig.(4), the calculated energy levels for ^{69}Ni obtained using jun 45 and jj44b effective interactions together with the experimental data are shown. The two interactions used in the present calculations are able to predict correct ground state spin as observed in experiment. The experimental values of ^{69}Ni isotope are all unconfirmed. Jun 45 and jj44b effective interactions are able to reproduce the correct sequence of the low-lying states $1/2^-$, $5/2^-$ and $9/2^+$. The calculation with jj44b are closer to the experimental values than jun 45 for these state. New high spins states have been assigned using jun 45 effective interaction these states are $11/2^-$, $15/2^-$, $1/2^+$ and $15/2^+$ with values 2.855 MeV, 3.403 MeV, and 3.008 MeV, respectively, while

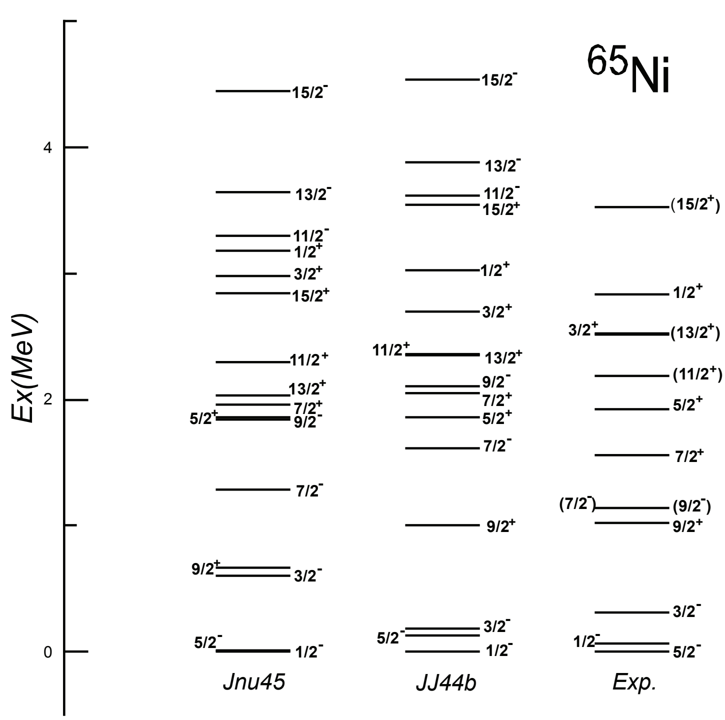

Fig.(2): Comparison of calculated and experimental low-lying spectra for ^{65}Ni isotope with jun 45 and jj44b effective interactions.

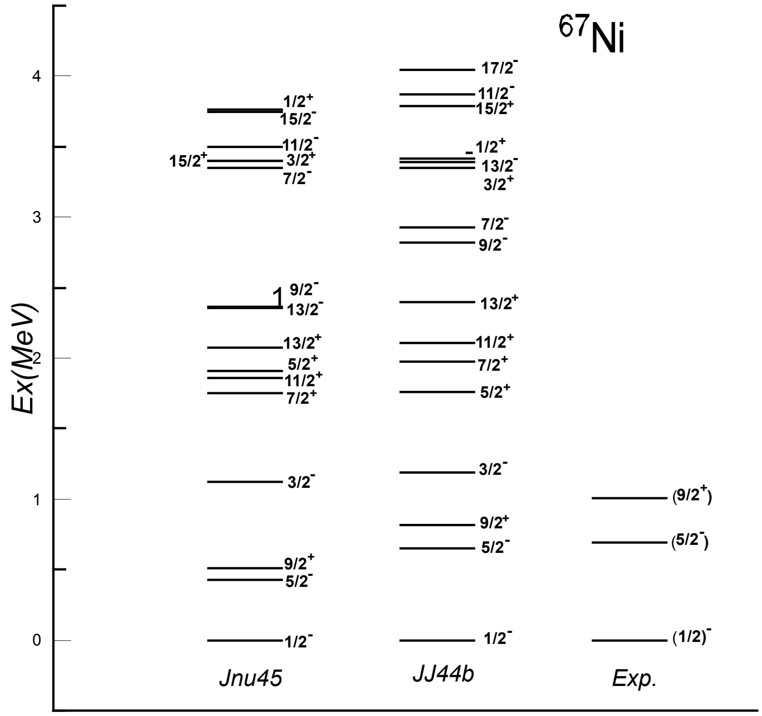

Fig.(3): Comparison of calculated and experimental low-lying spectra for ^{67}Ni isotope with jun 45 and jj44b effective interactions.

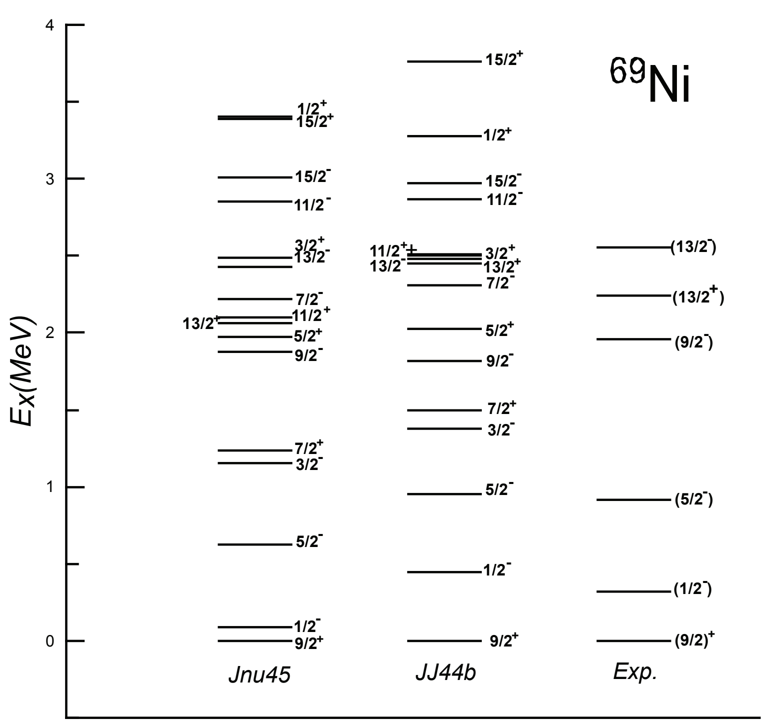

Fig.(4): Comparison of calculated and experimental low-lying spectra for ^{69}Ni isotope with jun 45 and jj44b effective interactions.

jj44b predict them at 2.870 MeV, 2.969 MeV, 3.275 MeV and 3.759 MeV, respectively.

The calculated low-lying energy levels for positive and negative parity states of ^{71}Ni and ^{73}Ni isotopes using jun 45 and jj44b effective interaction compared with the experimental data and is presented in Figs. (5) and (6), respectively. The ground state for both isotopes is correctly reproduced by using both effective interactions. The experimental data are unconfirmed for ^{71}Ni and ^{73}Ni isotopes. The ordering of the low-lying spin states for ^{71}Ni isotope are correctly reproduced by jj44b effective interaction, while ju45 predicts $1/2^-$ lower than $7/2^+$ which is in disagreement with the experimental data. The effective interaction jj44b reproduce the correct ordering of $7/2^+$ and $1/2^-$ states for ^{71}Ni isotope in comparison with the experimental data. The experimental data for the isotope ^{73}Ni is not available at the moment and once the observed experimental data are available one can judge which of the effective interactions used in the present work are more able to reproduce the experimental data.

4. Conclusion

The present work highlights the ability of the present shell model calculations for neutron-rich isotopes near ^{60}Ni and the challenges in the calculations due to high dimension of J-T scheme. In our work there is no restriction imposed on the valence nucleons and all bases were included in the calculations. A conclusion can be drawn that the effective interactions jun 45 and jj44b are adequate choice for nuclei lies in this mass region. The effective interactions jj44b is more consistent in reproducing the experimental data and the ordering of the low-lying spectra than jun 45 for the nuclei investigated in the present study.

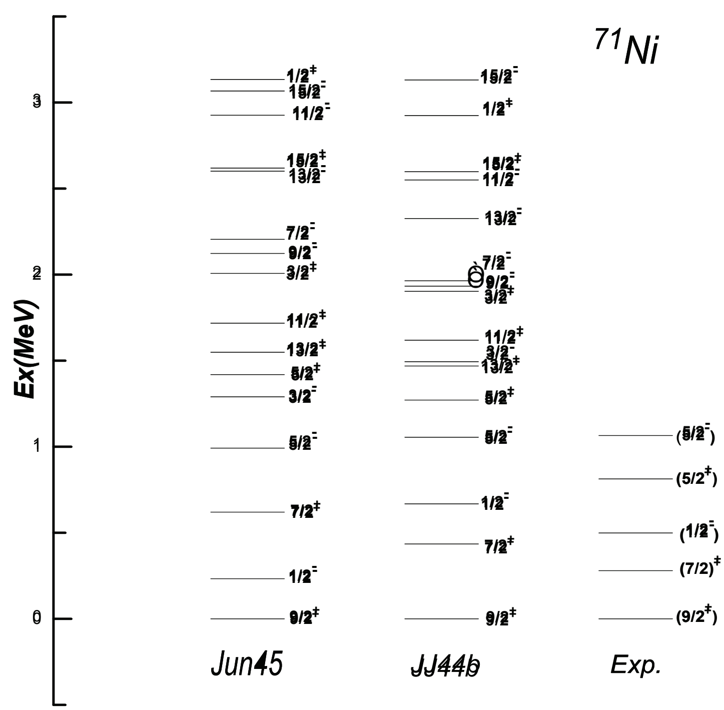

Fig.(5): Comparison of experimental and calculated low-lying spectra for ^{71}Ni isotope with jun 45 and jj44b effective interactions.

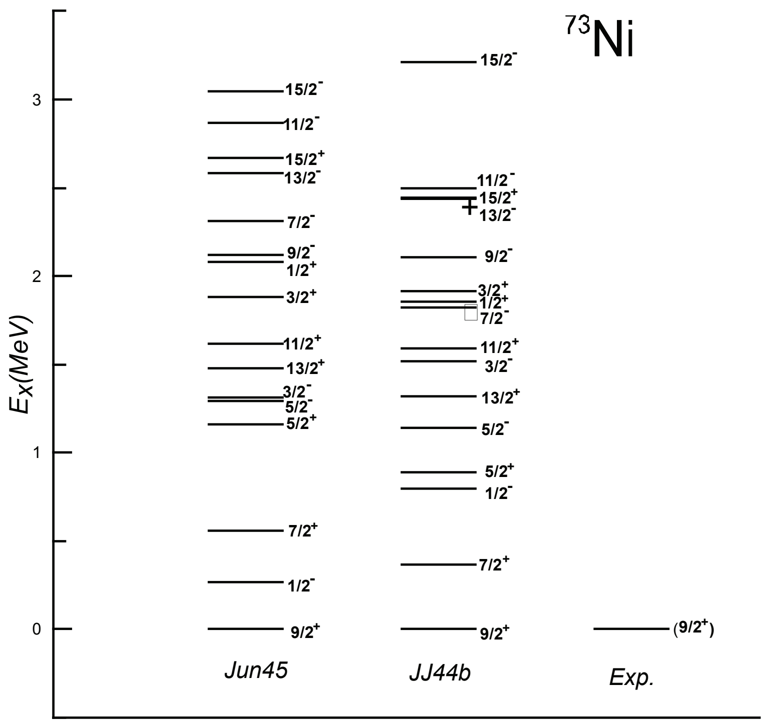

Fig.(6): Comparison of calculated and experimental low-lying spectra for ^{73}Ni isotope with jun 45 and jj44b effective interactions.

References

[1] M.G.Mayer, Phys.Rev.**75**, 1969 (1949).

[2] A.Albers *et al*., Phys.Rev.**C88**, 054314 (2013).

[3] F.A.Majeed, F.M.Hussain and A.O.M.Almayyali, Int.J.of Sci.Res.**11** (11), 2842 (2014).

[4] J.Diriken *et al*., Phys.Lett.**B 736**, 533 (2014).

[5] B.A.Brown, W.D.M.Rae, E.McDonald and M.Horoi, NuShellX@MSU,http://www.nscl.msu.edu/ brown/ resources/resources.html.

[6] M. Honma *et al*., Phys.Rev.C **80**, 064323 (2009).

[7] B.A.Brown (unpublished).

[8] ENSDF, Evaluated nuclear structure data file, database version 29-5-2015; accessed 13/3/2015.