Available online at www.dergipark.gov.tr/beuscitech

Journal of Science and Technology

E-ISSN 2146-7706

Study of the shell evolution effect on the nuclei around the ^{78}Ni core structure

Nadjet Laouet*, Fatima Benrachi, Habiba Guerraiche, Karima Benhizia

LPMPS Laboratory, Frères Mentouri Constantine-1 University, Route Ain El Bey 25017 Constantine (Algeria)

ARTICLE INFO

Article history:
Received 15 October 2019
Received in revised form 02 December 2019
Accepted 02 December 2019

Keywords:
Nuclear shell model
Doubly magic core ^{78}Ni
Monopole interaction
Nuclear structure properties
NuShellX@MSU code

ABSTRACT

The interactions between the core which is anymore inert and the valence nucleons play a very important role in the interpretation of nuclear properties far from stability. The work done in this study is based on the calculations of energy spectra and electromagnetic properties for even-even isotones with N=52, in the ^{78}Ni region. Based on the interaction *jj45apn* with the space model *jj45pn*, we have realized some modifications considering the monopole interaction and a new interaction called *jj45am* is introduced. The calculations are performed in the framework of the nuclear shell model using the *NuShellX@MSU* code. The shell evolution, studied by estimating the effective single-particle energies (SPEs) in this region, show an important influence on the nuclear structure properties. The obtained results using the new interaction *jj45am* are in agreement with the experimental data, and better than those given by the original one *jj45apn*.

1. Introduction

Nuclei close to doubly magic cores that are in the limit of the nuclear chart are good candidates to test new theoretical predictions in order to explain the experimental observations in such systems. Experimental studies and spectroscopic calculations, in these regions, can prove and expect new phenomena as the disappearance of some habitual magic numbers and the appearance of new ones (Dobaczewski et al., 1994; Otsuka et al., 2010). These observations may result from the so-called shell evolution. ^{78}Ni is one of the best exotic doubly magic cores, which is considered as the closest core to the neutron drip-line. This region offers the best opportunity to develop a comprehensive understanding of shell evolution.

In this context, we have studied N=52 isotones, which cover a large range from the proton drip line to the neutron one near ^{78}Ni core.

Indeed, there are few experimental data in the considered mass region. ^{78}Ni is an exotic nucleus situated in the limit of the nuclear chart and it is very difficult to realize experimental studies. The two neutrons in N=52 isotones are situated on $d_{5/2}$ shell for low excitation energies. For high ones, one or two neutrons can move to other orbits. These isotones have been studied by Czerwinski et al. (2013). In their work, the ^{86}Se and ^{88}Kr nuclei have been investigated following, respectively, spontaneous fissions of ^{248}Cm and ^{252}Cf by means of prompt-γ-ray-spectroscopy methods using the Gamma sphere Ge array (Czerwinski, 2013). In addition, they have predicted the Energies of the first 2^+ and 4^+ levels in the ^{82}Zn nucleus using systematics shown in Figure 1., that presents the calculated excitation systematics in comparison with the available experimental data (see (Czerwinski, 2013) for more details).

* *Corresponding author.* Nadjet LAOUET
E-mail: nadjet.laouet@umc.edu.dz

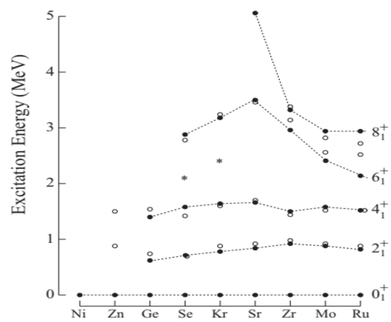


Figure 1. Calculated excitation systematic in comparison with the available experimental data (Czerwinski, 2013).

2. Theoretical framework

One of the most important phenomena, that is used to study such nuclear systems, is the monopole effect. This later it has been focused on after the discovering of new nuclei more and more exotic and the appearance of unexpected observation as the appearance of new magic numbers, as a result of shell evolution (Cortes and Zuker, 1979; Smirnova et al., 2010).

This effect comes from the interactions between the core and the valence nucleons (Sorlin and Porquet, 2008; Otsuka et al., 2010). In this approximation, a nuclear system can be presented in terms of a monopole and a multipole Hamiltonians.

$$H = H_m + H_M$$
$$H_m = \sum_s n_s \varepsilon_s + \sum_{s \le t} \left(a_{st} n_{st} + b_{st} T_{st} \right) \quad (1)$$

The monopole part is expressed as a function of single-particle energies (SPE ε_s, occupation n_{st} , isospin T_{st} operators, and V_j which presents an energy average over the spin J (Sorlin and Porquet, 2008; Poves and Zuker, 1981):

$$V^{pn}_{j_\tau j_{\tau'}} = \frac{\sum_J (2J+1) E_J \left(j_\tau j_{\tau'} \right)}{\sum_J (2J+1)} \quad (2)$$

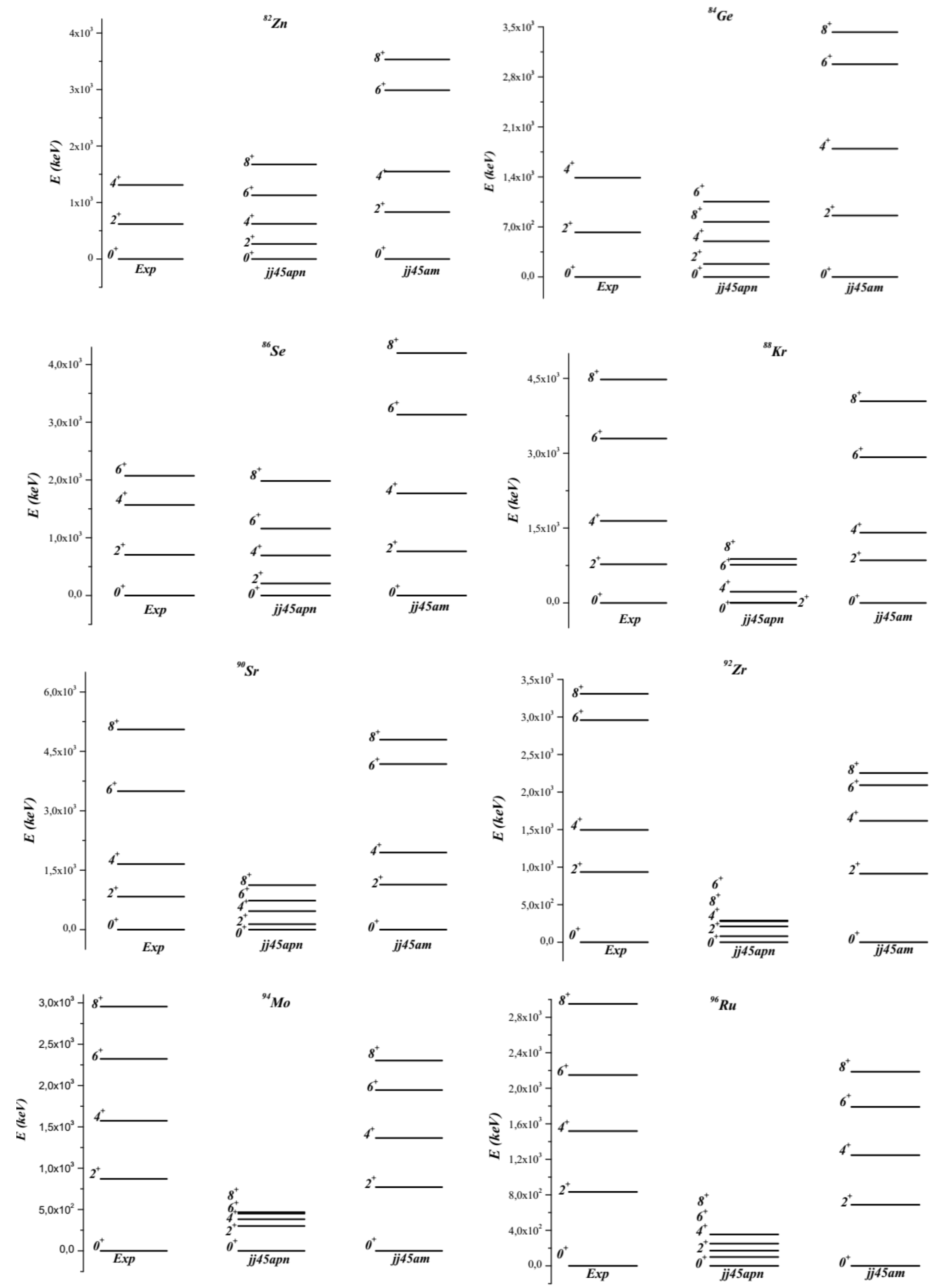
The TBME of the using interaction are modified taking in consideration the proton-proton, neutron-neutron and proton-neutron monopole effects for even-even N=52 nuclei in the ^{78}Ni region and a new interaction is introduced.

$$\left\langle j_\tau j_{\tau'} \middle| V_{jj45am} \middle| j_\tau j_{\tau'} \right\rangle_J = \left\langle j_\tau j_{\tau'} \middle| V_{jj45apn} \middle| j_\tau j_{\tau'} \right\rangle + monopole\ term$$

3. Results and discussion

For our calculations, we have used jj45pn, which contains π ($1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$ and $1g_{9/2}$) orbits for protons and ν ($1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$ and $1h_{11/2}$) for neutrons, as an SPS. The SPEs were taken from the experimental data and from Grawe et al., for some shells (nndc, 2019; Grawe et al., 2007). The used interaction is obtained starting from *jj45apn* original interaction, based on the G matrix for ^{132}Sn region (Jenson at al., 1995; Rejmund et al., 2016), considering the monopole effect.

One of the well-known codes, the NuShellX@MSU code is used to carry out the spectroscopic calculations achieved in this work. It presents a development of NuShellX code: which contains a set of computer codes written by Rae (Brown and Rae, 2014). The calculation results in comparison with the experimental data are reported in Figure 2.



^{82}Zn
^{84}Ge
^{86}Se
^{88}Kr
^{90}Sr
^{92}Zr
^{94}Mo
^{96}Ru
E (keV)
Exp
jj45apn
jj45am

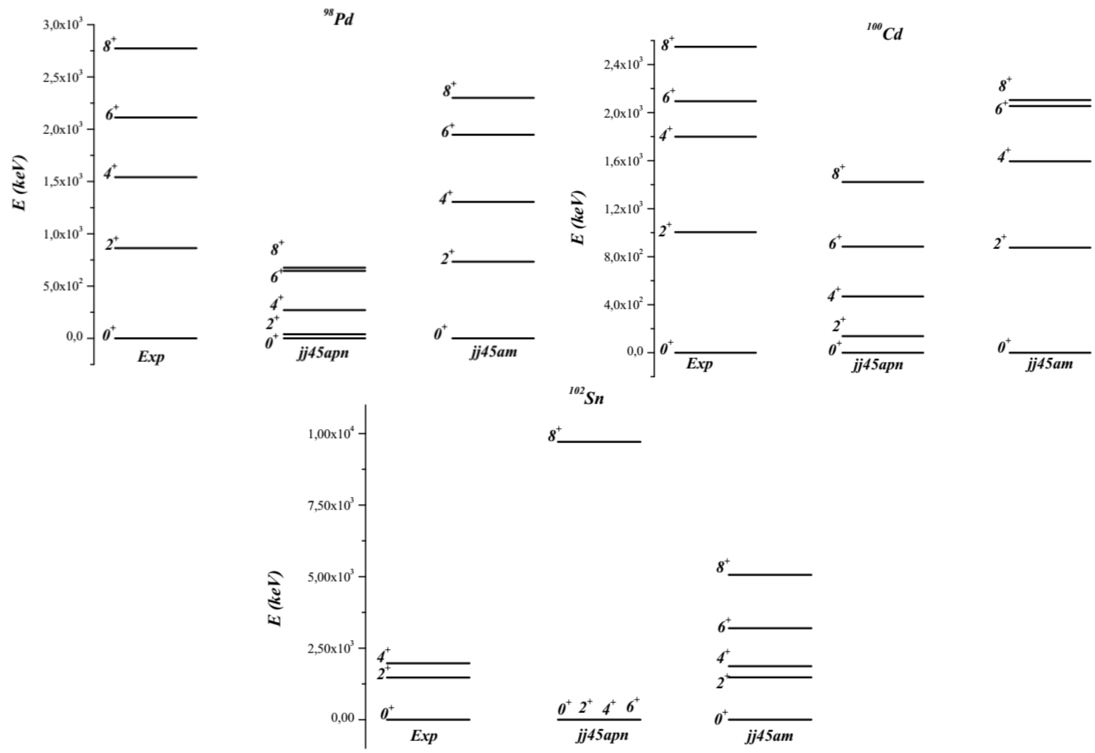


Figure 2. Calculated energetic spectra using jj45apn and jj45am interactions in comparison with the available experimental data (nndc, 2019).

These spectra are used to plot the energetic systematics for N=52 isotones with Z=30-50.

The results are shown in Figure 3:

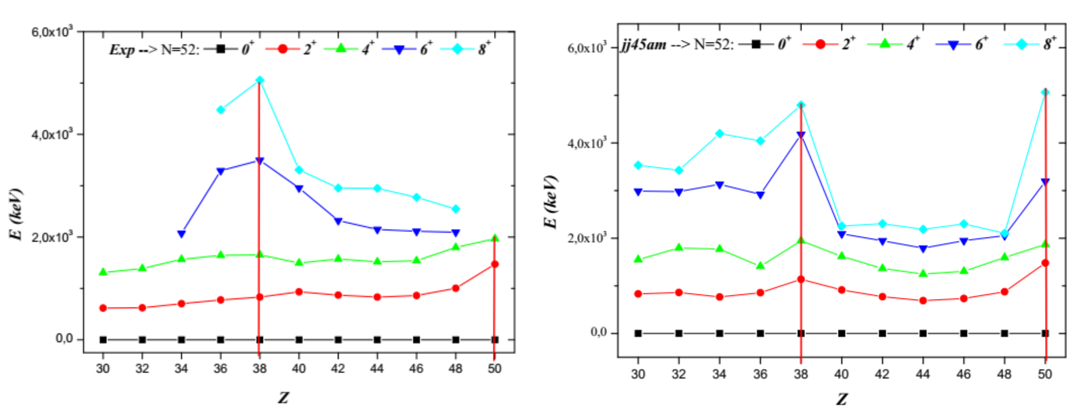


Figure 3. Calculated systematics by means of jj45am (right) in comparison with the experimental ones (left), in N=52 isotones.

For the experimental energies (left), the spectra show a peak for Z=38 isotope. The peak is clear for 4^+, 6^+ and 8^+. The available data for 2^+ and 4^+ show also a peak for Z=50. These two peaks are clear in the calculated systematics (right). The peak is clear for all excited states.

The explanation of the Z=50 peak is clear as this charge number is a habitual magic number. The other peak in Z=38 is a sign of a possible new magic number which can be a result of shell evolution in ^{78}Ni.

4. Conclusions

This work is based on the energetic spectra calculations, for even-even N=52 isotones, with two neutrons and few protons in their valence spaces. The calculations are realized in the framework of the nuclear shell model, by means of *NuShellX@MSU* nuclear structure code. Using the *jj45apn* original interaction of the code, we carried out some modifications based on the monopole interaction to get *jj45am* one.

Most of the calculated spins and parities of the studied nuclei are in agreement with the experimental ones. The excited states calculated using the elaborated interaction are close to the available experimental data, in comparison with those calculated using the original interaction without monopole terms. The calculated results give a prove of the existence of the new magic number Z=38. This may an important indication of the role of the monopole interaction consideration on the explanation of spectroscopic properties.

Acknowledgements

Authors of this article thanks to the organizers of the "XII. International Conference on Nuclear Structure Properties NSP 2019, October 11th-13th 2019, Bitlis-Turkey', for the organization and the support provided during the conference. Special thanks are owed to B. A. Brown for his help in providing us with the NuShellX@MSU code (Linux Version), and to M. H. Jensen, for the documents and the information provided about the interaction *jj45apn*.

References

Brown, B. A., Rae, W. D. M. 2014. The Shell-Model Code NuShellX@MSU. Nuclear Data Sheets, 120, 115-118.

Cortes, A., Zuker, A. P. 1979. Self-Consistency and many body monopole forces in shell model calculations. Physics Letters, 84B, 25-30.

Czerwinski, M. et al. 2013. Yrast excitations in the neutron-rich N = 52 isotones. Physical Review C, 88, 044314 1-13.

Dobaczewski, J., Hamamoto, I., Nazarewicz , W., Sheikh, J. A. 1994. Nuclear Shell Structure at Particle Drip Lines. Physical Review Letters, 72, 981-984.

Grawe, H., Langanke, K., Martinez-Pinedo, G. 2007. Nuclear structure and astrophysics. Reports on Progress in Physics, 70, 1525-1585.

Hjorth-Jensen, M., Kuo, T.T.S., Osnes, E. 1995. Realistic effective interaction for nuclear systems. Physcs Reports, 261, 125-270.

https://www.nndc.bnl.gov/ensdf/ensdf/xundl.jsp.

Otsuka, T., Suzuki, T., Fujimoto, R., Grawe, H., Akaishi, Y. 2005. Evolution of Nuclear Shells due to the Tensor Force. Physical Review Letters, 95, 232502 1-4.

Otsuka, T., Suzuki, T., Holt, J. D., Schwenk, A., Akaishi, Y. 2010. Three-body forces and the limit of oxygen isotopes. Physical Review Letters, 105, 021501 1-5.

Poves, A., Zuker, A. P. 1981. Theoretical spectroscopy and the FP shell. Physics Reports, 70, 235-314.

Rejmund, M. et al., 2016. Structural changes at large angular momentum in nuclear rich 121-123Cd. Physical Review C, 93, 024312 1-6.

Smirnova, N. A., Bally, B., Heyde, K., Nowacki, F., Sieja K. 2010. Shell evolution and nuclear forces. Physics Letters B, 686, 109-113.

Sorlin, O., Porquet, M. G. 2008. Nuclear Magic numbers: New features far from stability. Progress in Particle and Nuclear Physics, 61, 602-673.