DESCRIPTION OF LIGHT NUCLEI ($10 \leqslant Z, N \leqslant 18$) WITHIN THE MULTIPARTICLE–MULTIHOLE GOGNY ENERGY DENSITY FUNCTIONAL*

J. Le Bloas, N. Pillet, J.-M. Daugas, M. Dupuis

CEA, DAM, DIF, 91297 Arpajon, France

(Received January 15, 2013)

In this work, we report a few examples of excitation energies, magnetic and quadrupole moments as well as $B(M1)$ and $B(E2)$ transition probabilities calculated within the multiparticle–multihole (mp–mh) configuration mixing approach [N. Pillet, J.-F. Berger, E. Caurier, *Phys. Rev.* **C78**, 024305 (2008); N. Pillet *et al.*, *Phys. Rev.* **C85**, 044315 (2012)], for sd-shell even–even nuclei with $10 \leqslant Z$, $N \leqslant 18$. The D1S Gogny effective interaction has been used. Only low-lying positive parity states have been considered. A very satisfactory agreement is obtained with experiment for energies, magnetic moments and $B(M1)$ transition probabilities. The calculated $B(E2)$ transition probabilities between 2_1^+ and 0_1^+ states, 4_1^+ and 2_1^+ states reproduce the experimental trends along the isotonic and isotopic chains with the good order of magnitude.

DOI:10.5506/APhysPolB.44.299
PACS numbers: 21.60.Jz, 21.30.Fe, 23.20.Lv, 27.60.+t

1. Introduction

The present work follows a recent study [1], focussed on the low-lying positive parity states in Si isotopes of the sd-shell, that demonstrated the capability of the mp–mh configuration mixing approach to reproduce experimental excitation energies with a reasonable accuracy. The D1S Gogny interaction was used. The formalism of this approach is presented in Ref. [2]. The present study extends the one of Ref. [1] in two directions: Ne, Mg, S and Ar isotopes are considered and more observables are calculated. More precisely, one studies magnetic and quadrupole moments, $B(M1)$ and $B(E2)$ transition probabilities that enable to test the correlation content of the mp–mh configuration mixing wave-functions. Calculations are done within the same assumptions as in Ref. [1]. In particular, the configuration mixing

* Presented at the Zakopane Conference on Nuclear Physics “Extremes of the Nuclear Landscape”, Zakopane, Poland, August 27–September 2, 2012.

is done in the full *sd*-shell, all the multiple particle–hole excitations allowed by symmetry conservation being included (up to $12p$–$12h$ depending on the nucleus). Our results, compared to experimental data, will be presented in the next section. In Sec. 3, the conclusion is given.

2. Study of Ne, Mg, Si, S and Ar isotopes

Our analysis have focussed on the properties of 2_1^+ and 4_1^+ states in Ne, Mg, Si, S and Ar even–even isotopes belonging to the *sd*-shell. In Fig. 1 (a), one displays a comparison between experimental and calculated (mp–mh) excitation energies of the 2_1^+ states. The same plot for 4_1^+ states is shown in Fig. 1 (b). Only theoretical results having an experimental counterpart are displayed. A very good agreement between the mp–mh configuration mixing results and the experimental data is obtained, except for the two isotopes ^{30}Si and its mirror nucleus ^{30}S, for which one gets a global energy shift (~ 2.5 MeV for ^{30}Si and ~ 2 MeV for ^{30}S) not only for 2_1^+ and 4_1^+ states

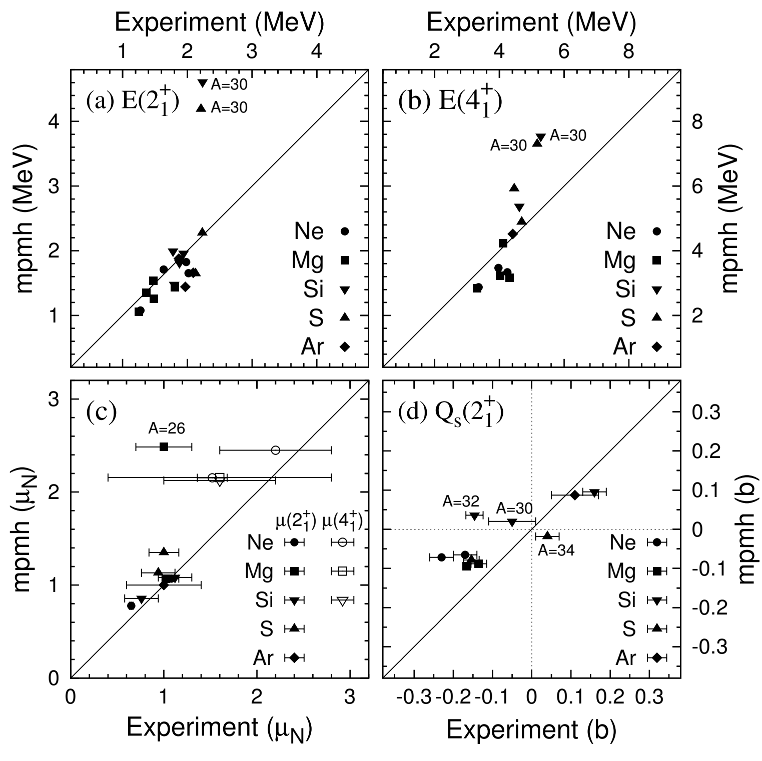

Fig. 1. Comparison between (a), (b) experimental and calculated (mp–mh) excitation energies, (c) magnetic moments of 2_1^+ and 4_1^+ states and (d) spectroscopic quadrupole moments Q_s for 2_1^+. For some results the mass number is mentioned.

but on the whole spectrum. The case of ^{30}Si has already been discussed in Ref. [1]. In a consistent way, the same phenomenon occurs in the mirror nucleus. It is interpreted in terms of the lack of a tensor term in the D1S Gogny interaction, in particular in the $T = 0$ component.

The magnetic dipole moment μ is an observable usually studied to emphasize the single particle nature of a state. The spectroscopic quadrupole moment Q_{s} constitutes a measure of the collectivity of a nuclear state. Both observables test in a very fine way the correlation content of wave-functions. They are presented in Fig. 1, panels (c) and (d) respectively. The magnetic moments, associated with the 2_1^+ states (full symbols) and 4_1^+ states (open symbols), are compared with experiment. Except for the ^{26}Mg isotope for which the magnetic moment differs from experiment by a factor of ~ 2.5, all the magnetic moments associated with the 2_1^+ states are found in a very good agreement with experiment. In the case of 4_1^+ states, the calculated values are within the experimental error bars.

Concerning the spectroscopic quadrupole moments of 2_1^+ states, one gets systematically smaller values than experiment. However, except in the case of ^{32}Si and for two values close to zero, the good sign is obtained. The difference with experiment may be attributed to the size of the valence space used in this study that may be too small to exhaust the quadrupole strength.

To complete the description of those states, calculations of electromagnetic transition probabilities, $B(E2)$ and $B(M1)$, have also been performed. As an example, in Fig. 2, one presents $B(E2\,;\,2_1^+ \to 0_1^+)$ values for Ar isotopes (top left) and $N = 14$ isotones (top right) and $B(E2\,;\,4_1^+ \to 2_1^+)$ values for Si isotopes (bottom left) and $N = 14$ isotones (bottom right). Experimental data are indicated in full circles for comparison. On the one hand, the *mp–mh* configuration mixing calculations, represented by full squares, are systematically lower than experiment, by a factor ~ 3 (pointed out by the enhanced open squares in Fig. 2) for the $B(E2\,;\,2_1^+ \to 0_1^+)$, and less for the $B(E2\,;\,4_1^+ \to 2_1^+)$. Such a systematic underestimation is also interpreted in terms of the size of the valence space used in this study. An increase of the valence space is expected to increase the collectivity of the $E2$ transitions and hence the $B(E2)$ values. The agreement between *mp–mh* configuration mixing calculations and the experimental data are better for the $B(E2\,;\,4_1^+ \to 2_1^+)$ values than for the $B(E2\,;\,2_1^+ \to 0_1^+)$ ones. The 0_1^+ states seem to be more affected than the excited states. One remarks that eventhough the excitation energies in ^{30}Si have been found shifted by ~ 2.5 MeV, the transition probability $B(E2\,;\,4_1^+ \to 2_1^+)$ is found within the same accuracy than for other nuclei. On the other hand, from Fig. 2, one sees that experimental trends are well reproduced by our calculations. The *mp–mh* configuration mixing method is able to correctly account for the structure of transition probabilities. Besides, a factor of ~ 3 on such kind of observables is a very encouraging result.

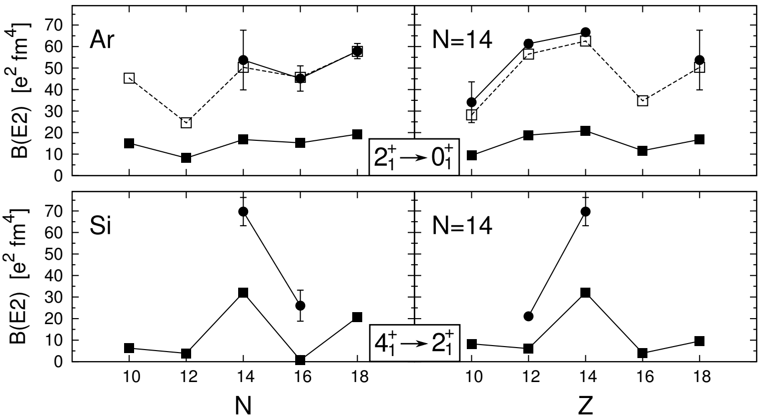

Fig. 2. Transition probabilities $B(E2\,;\,2_1^+ \rightarrow 0_1^+)$ in the Ar isotopes (top left) and the $N=14$ isotones (top right) and $B(E2\,;\,4_1^+ \rightarrow 2_1^+)$ in the Si isotopes (bottom left) and the $N=14$ isotones (bottom right). Theoretical results (*mp–mh*) are in full squares (open squares when enhanced by a factor of 3) and experimental data are in full circles.

Finally, $B(M1)$ transition probabilities have been calculated for 15 experimental transitions implying low-lying states. Except for four cases, the calculated $B(M1)$ values have, at least, the good order of magnitude. In Table I, typical examples of such cases are listed. The present approach describes the large variety of orders of magnitude for the $B(M1)$ transition probabilities that range from 10^{-6} to 10^{-1} in Weisskopf unit.

TABLE I

A few $B(M1)$ transition probabilities (in Weisskopf unit) in *sd*-shell nuclei calculated within the *mp–mh* approach. Experimental values are indicated.

Nucl.	Transition	Exp. [W.u.]	*mp-mh* [W.u.]
^{24}Mg	$3_1^+ \rightarrow 2_1^+$	2.1×10^{-5} (1.1)	4.6×10^{-5}
	$2_2^+ \rightarrow 2_1^+$	9×10^{-6} (8)	7×10^{-6}
^{26}Mg	$3_1^+ \rightarrow 2_1^+$	0.00102 (15)	0.00375
	$2_2^+ \rightarrow 2_1^+$	0.097 (12)	0.066
^{26}Si	$2_2^+ \rightarrow 2_1^+$	0.10 (3)	0.07
^{30}Si	$2_2^+ \rightarrow 2_1^+$	0.09 (3)	0.19
^{34}S	$2_2^+ \rightarrow 2_1^+$	0.052 (3)	0.059
	$2_3^+ \rightarrow 2_1^+$	0.015 (3)	0.010
^{34}Ar	$2_2^+ \rightarrow 2_1^+$	0.058 (12)	0.030

3. Conclusion

In this work, the spectroscopic properties of Ne, Mg, Si, S and Ar isotopes of the *sd*-shell have been studied. The calculations of electromagnetic moments and transition probabilities have demonstrated the relevance of the *mp–mh* configuration mixing approach, using the D1S Gogny interaction, to describe observables beyond excitation energies. For $E2$ transitions between 2_1^+ states and 0_1^+ ground states, for which experimental trends are reproduced within a factor of ~ 3, one expects that an enlargement of the valence space would improve the agreement with the experimental transition probabilities.

REFERENCES

[1] N. Pillet *et al.*, *Phys. Rev.* **C85**, 044315 (2012).

[2] N. Pillet, J.-F. Berger, E. Caurier, *Phys. Rev.* **C78**, 024305 (2008).