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Description of the Spectroscopic Properties of ^{26}Si

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Abstract. We are interested in our work to the study of the ^{26}Si energy spectrum in the shell model framework using the PSDPF interaction. Silicon has a significant astrophysical interest, which plays a crucial role in the comprehension of nucleosynthesis, especially, the galactic chemical evolution. The ^{26}Si is important for determining the ^{25}Al$(p,\gamma)^{26}$Si reaction rate that involves the determination of the spin/parity level assignments, especially, those at high excitation energies above the proton threshold. The energy spectrum of ^{26}Si is not well known and it is experimentally difficult to reach because it has $N < Z$. We use the PSDPF interaction to describe the complete energy spectrum of both positive and negative parity states of the ^{26}Si, up to $\sim$ 9 MeV, then compared them to available experimental data. The obtained results are in quite good agreement with experiment, therefore, many predictions were proposed.

1 Introduction

Silicon is the eight most abundant elements in the universe; it plays an important role in understanding nucleosynthesis and galactic chemical evolution (GCE) [1]. This element has 23 known isotopes, with mass number ranging from 22 to 44 [2], seven of them have an astrophysical interest, $^{24\text{–}30}$Si. Most of them are produced through the rapid proton capture (rp-process). Silicon burning is a very short sequence and the final stage of nuclear fusion reactions that occur in massive stars with a minimum of about 8–11 solar masses [3]. Nuclear shell model (SM) study focuses on the description of the energy spectra and electromagnetic properties using a compatible effective interaction with an appropriate model space. These properties are a severe test of the interaction. This model can serve many experimental studies, especially, those concentrated on astrophysics.

The aim of this work is to calculate the complete energy spectrum of ^{26}Si in order to determine the spin/parity assignments of state of astrophysical interest above of the proton threshold 5513.8 keV [2]. We performed a shell model calculation employing the SM Nathan code [4, 5] and using the $(0+1)$ $\hbar\omega$ PSDPF effective interaction [6, 7].

2 Results and Discussion

2.1 PSDPF interaction

The experimental low excitation energy spectra [2] of sd shell nuclei, with a number of protons and neutrons comprises between 8 and 20, are characterized by the coexistence of normal positive parity states (called also 0 $\hbar\omega$ states) and the intruder negative parity (named 1 $\hbar\omega$ states). The positive-parity levels are well described using the sd valence space with ^{16}O core, where the valence nucleons move freely in the sd shell. The USD interaction or the adapted ones USDA/B [8, 9] were used to describe the normal states. Concerning the intruders, the full p-sd-pf valence space and the PSDPF interaction can be used with ^{4}He inert core.

The PSDPF interaction has a great success in describing the 0 and 1 $\hbar\omega$ states in nuclei throughout the sd shell. This interaction has been used to calculate the spectroscopic properties of many sd nuclei and some isotopic chains.

2.2 The ^{26}Si spectrum

The ^{26}Si spectrum is not well known and it is experimentally difficult to reach because it has $N < Z$. We used the PSDPF interaction to determine the J^{π} assignments in this neutron deficient nucleus ^{26}Si. We discuss the J_i^{π} certainties, uncertainties and the undetermined states (those without J_i^{π}) for the various energy regions.

We have calculated the excitation energy from 0 to $\sim$ 10 MeV. The comparison of the obtained results to experimental data [10–17] is shown in Table 1.

The excitation energies of states of ^{26}Si are presented in column 1, its corresponding known J^{π} values are given in column 2. The shell model excitation energies, which are ordered according to the level sequences in the ^{26}Si experimental spectrum, are given in column 3, whose J_i^{π} values are represented in column 4, 'i' denote the number of levels for a given J^{π} value. The deference in energy are shown in column 5.

The ^{26}Si spectrum contains, up to 8.7 MeV, 85 theoretical levels against 49 experimental ones, 15 of them are certain states, having well known J^{π}. There are 25 uncertain states in this spectrum, which are in parenthesis with doubt J^{π} assignments and have to be confirmed. 9 states have no J^{π} assignments; predictions of their J^{π} assignments based on shell model calculations are essential.

We remark in Table 1, that we have a one to one correspondence between calculated and experimental states. The calculated levels are in good agreement with experiment. Some discrepancies were obtained for states that are predicted higher in energy then their experimental counterparts with more than 400 keV, this means that they have a collective contribution.

We confirmed all the uncertain states like (3^+) at 3.758 MeV, 3^+ at 4.188 MeV, (4^+) at 4.446 MeV and (4^+) at 4.797 MeV to have $J_i^{\pi} = 3_1^+, 3_2^+, 4_1^+, 3_2^+$ calculated at 3.99, 4.389, 4.397 and 5.013 MeV, respectively. We also proposed

Table 1. Comparison experimental [10–17] versus calculated energy spectra of the ^{26}Si

E (Si)		Shell model		
E_{exp} (MeV)	J^π	E_{th} (MeV)	J_i^π	$\Delta E = E_{th} - E_{exp}$
0	0^+	0	$0^+{}_1$	0
1.797	2^+	1.878	$2^+{}_1$	0.081
2.787	2^+	3.042	$2^+{}_2$	0.255
3.336	0^+	3.829	$0^+{}_2$	0.493
3.758	(3^+)	3.990	$3^+{}_1$	0.232
3.842				
4.139	2^+	4.590	$2^+{}_3$	0.451
4.188	(3^+)	4.389	$3^+{}_2$	0.201
4.446	(4^+)	4.397	$4^+{}_1$	-0.049
4.797	(4^+)	5.013	$4^+{}_2$	0.216
4.811	(2^+)	4.944	$2^+{}_4$	0.133
4.831	(0^+)	4.909	$0^+{}_3$	0.078
5.148	2^+	5.500	$2^+{}_5$	0.352
5.289	4^+	5.553	$4^+{}_3$	0.264
5.518	(4^+)	5.925	$4^+{}_4$	0.407
5.676	1^+	5.693	$1^+{}_1$	0.017
5.890	0^+			
5.929	3^+	6.283	$3^+{}_3$	0.354
5.946	(0^+)	6.278	$0^+{}_4$	0.332
6.295	2^+	6.668	$2^+{}_6$	0.373
6.383	(2^+)	6.815	$4^+{}_5$	0.432
6.461	0^+	6.668	$1^+{}_2$	0.207
6.765		6.663	$1^-{}_1$	-0.103
6.787	3^-	6.716	$3^-{}_1$	-0.071
6.810		6.736	$2^-{}_1$	-0.074
6.880	(0^+)	8.070	$0^+{}_5$	1.190
7.019	(3^+)	7.341	$3^+{}_4$	0.323
7.154	2^+	6.936	$2^+{}_7$	-0.218
7.198	(5^+)	7.086	$5^+{}_1$	-0.112
7.418	(4^+)	7.530	$4^+{}_6$	0.112
7.496	2^+	7.214	$2^+{}_8$	-0.282
7.522	(5^-)	7.447	$5^+{}_2$	-0.075
7.606		7.697	$2^-{}_2$	0.091
7.674	(2^+)	7.575	$2^+{}_9$	-0.099
7.701	(3^-)	7.495	$3^-{}_2$	-0.206
7.886	(1^-)	7.492	$1^-{}_2$	-0.394
7.921		7.734	$1^-{}_3$	-0.187
7.962		7.898	$4^-{}_1$	-0.064
8.008	(3^+)	7.700	$3^+{}_5$	-0.308
8.144	$(1^-,2^+)$	7.930	$1^+{}_3$	0.214
8.222	(1^-)	8.077	$1^-{}_4$	-0.145

Table 1. Continue

E (Si)		Shell model		
E_{exp} (MeV)	J^π	E_{th} (MeV)	J_i^π	$\Delta E = E_{\text{th}} - E_{\text{exp}}$
8.254		7.937	$3^-{}_3$	-0.317
8.269	(2^+)	8.379	$2^+{}_{10}$	0.110
8.282		7.951	$2^-{}_3$	-0.331
8.356	(3^+)	8.301	$3^+{}_6$	-0.055
8.431		8.160	$2^-{}_4$	-0.271
8.558	(2^+)	8.993	$2^+{}_{11}$	0.435
8.689	$(1^-,2^+)$	8.443	$1^+{}_4$	-0.246

theoretical candidates for states observed at: 6.766, 6.811, 7.607, 7.701, 7.734, 8.254, 8.283 and 8.431 MeV to have $J_i^\pi = 1_1^-, 2_1^-, 2_2^-, 3_2^-, 1_3^-, 3_3^-, 2_3^-$ and 2_4^- calculated at 6.663, 6.736, 7.697, 7.495, 7.734, 7.937, 7.951 and 8.160 MeV. These J_i^π assignments are also based on the comparison to the previous theoretical calculation in [18].

For illustration, we present the differences between theoretical and experimental excitation energies (delta) in Figure 1. As seen, this difference varies

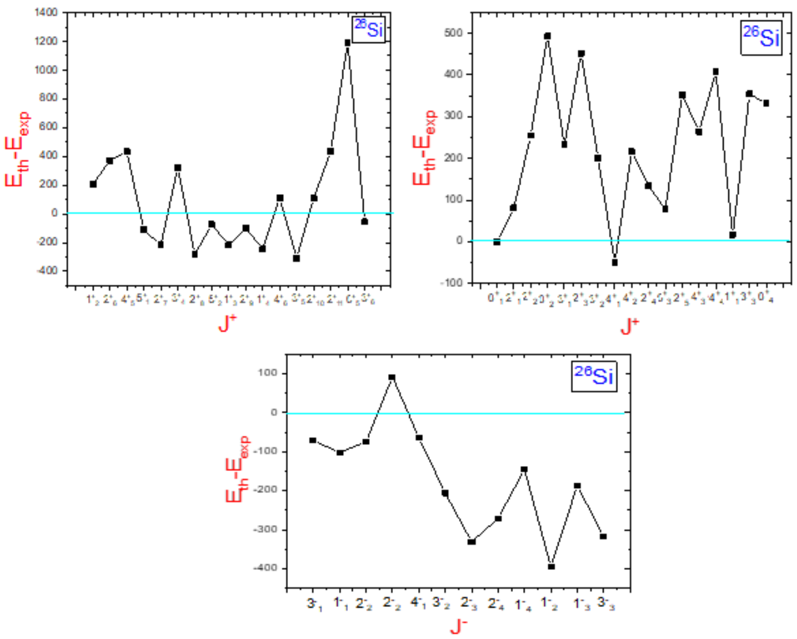

Figure 1. Differences between theoretical and experimental excitation energies of ^{26}Si.

from 17 keV for 1_1^+ to 1190 keV for 0_5^+. For the positive parity states, a good agreement between theory and experiment can be seen for most of levels, except for these higher predicted states 0_2^+, 0_5^+, 2_3^+ and 2_{11}^+. This is a sign of collectivity, which is expected for this spin numbering. Concerning the negative parity states here, our results agree quite well with experiment for practically all states.

3 Conclusion

We studied here, the energy spectrum of the ^{26}Si nucleus using the PSDPF interaction in order to determine the J^π of the ambiguous states and to predict spins and/or parities assignments for the unknown states. This nucleus has an astrophysical interest as it is produced through the rp-process $^{25}\mathrm{Al}(p,\gamma)^{26}\mathrm{Si}$ reaction. The obtained results show a good agreement theory versus experiment for the excitation energy spectrum. This study led us to confirm the uncertain states (uncertain J^π) and to predict J^π assignments for the unidentified ones (unknown J^π), especially, for those having a significant astrophysical importance, with energies above of the proton threshold 5513.8 keV. The $^{25}\mathrm{Al}(p,\gamma)^{26}\mathrm{Si}$ stellar reaction rate can now be calculated based on our study.

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