Shell model study of low lying states in Zn isotopes

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Introduction

The structure of nuclei in mass A∼60 region is primarily determined by the negative parity $1p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$ and the positive parity $1g_{9/2}$ orbitals. The unique parity intruder $1g_{9/2}$ orbital plays an important role even at low excitation energy as evident from single particle states observed in odd Zn isotopes. However, particle-hole excitation across the N=Z=28 shell gap may also be expected whence $1f_{7/2}$ plays a major role in influencing the structure at low as well as at high spin. With two protons and two to ten neutrons outside the N=Z=28 shell, transition from single particle to collective behavior is expected in ^{60,62,64,66}Zn isotopes. The presence of first excited 2^+ state at around 1 MeV and a triplet of 0^+, 2^+, and 4^+ states at around 2 MeV has led to the description of some of these isotopes in terms of an-harmonic vibrator. Here we report on shell model calculation of low lying energy levels, B(E2) values, mean lifetime values, quadrupole moments and occupation number in even-even $^{60-66}$Zn isotopes. Results of the calculation are compared with the existing experimental data.

Shell Model Calculation

Shell model calculation has been performed for even-even ^{60,62,64,66}Zn using NuShellX [1] code for Windows platform in $f_{5/2}pg_{9/2}$ model space with two different effective interactions, viz. JUN45[2] and jj44b[3]. In this model space, the core is doubly-magic ^{56}Ni and the calculation has been carried out without truncation in the valence space with active orbitals $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$ and $1g_{9/2}$. Reduced transition probabilities have been calculated using two different sets of effective proton(e_π) and neutron charge(e_ν). The set with $e_\pi = 1.5e$, e_ν=0.5e is termed as SM I and that with $e_\pi = 1.8e$, $e_\nu = 0.65e$ is called SM II. The calculated level energies, B(E2) values, mean lifetimes and quadrupole moments from two interactions are compared with the available experimental data[4–6].

Results and Discussion

In N=Z=30, ^{60}Zn, the calculated level energy using jj44b interaction shows a very good agreement with the experimental data, whereas the result from JUN45 interaction shows moderate agreement. B(E2) values, mean life time and quadrupole moments calculated from the two interactions are given in Table I(e_π=1.5,e_ν=0.5). Experimental data on B(E2), lifetime etc. are not presently available for this nuclei. For ^{62}Zn, both the interactions predict correct ordering of the low lying J=0^+, 2_1^+, 2_2^+ and 4_1^+ states. Level energies calculated from jj44b interaction are in good agreement than that of the JUN45. B(E2) values calculated from SM I using both the JUN45 and jj44b under-predicts the experimental data whereas for SM II the evaluated results are close to the experimental values.

The low lying spectra of ^{64}Zn exhibit familiar pattern of spherical vibrator, the triplet of 2_2^+, 0_2^+ and 4_1^+ states lying at about twice the energy of 2_1^+. However, the experimental B(E2) values disqualify them to be of two phonon character[7]. In the present calculation, ordering of the low lying J=0^+, 2_1^+, 2_2^+ and 4_1^+ states are well predicted by both the interactions. However level energies calculated using jj44b gives better agreement compared to JUN45 interaction. B(E2) values calculated for both SMI and SMII are not satisfactory, though B(E2,$4_1 \rightarrow 2_1$,SMI) and B(E2,$2_1 \rightarrow 0_1$,SMII) values matches well, the trend of falling B(E2) values is not reproduced. As in the earlier case, in ^{66}Zn jj44b interaction gives better re-

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TABLE I: Calculated excitation energies(MeV), B(E2)(W.u.), mean-lifetime(psec) and quadrupole moment(e-fm^2) of few y-rast states of ^{60}Zn using the jj44b and JUN45 interaction.

$\mathbf{I^\pi}$	**Exp. energy**	**Theo. energy**		**B(E2)**		**Mean Lifetime**		**Q. moment**	
		jj44b	JUN45	jj44b	JUN45	jj44b	JUN45	jj4 4b	JUN45
2_1^+	1.004	0.999	0.996	11.40	10.83	5.171	5.450	–25.72	-24.72
4_1^+	2.193	2.112	2.641	13.70	12.69	2.44	0.37	-33.75	-32.17
6_1^+	3.808	3.831	4.568	11.9	11.83	0.322	0.180	-37.75	-35.88
8_1^+	5.292	5.354	6.752	8.48	7.34	0.830	0.158	–37.05	-40.44

sults in terms of energy values as well as in ordering of the levels. In terms of B(E2) values, quadrupole moments and lifetime values, the results of the calculation shows a moderate agreement with the data.

Conclusion

To summarize we have performed shell model calculation in the fpg model space for studying low lying states in ^{60,62,64,66}Zn isotopes. Comparison with the experimental results shows that the low lying states are reproduced quite reliably. The interaction jj44b is seen to have better prediction as compared to JUN45 in our calculations. However some discrepancies in energy values, their ordering and B(E2) values occur using both of the interactions. This calls for better interactions for nuclei in this model space and/or inclusion of $1f_{7/2}$ below ^{56}Ni for finer agreement, thus using ^{40,48}Ca as core, which is computationally not feasible at present.

TABLE II: Comparision of calculated B(E2,$2_1^+ \rightarrow 0_1^+$) and B(E2,$4_1^+ \rightarrow 2_1^+$) values with the experimental data.

Nuclei(I^π)	B(E2)[W.u]				
	Expt.	JUN45		jj44b	
		SM I	SM II	SM I	SM II
^{60}Zn(2_1^+)	-	10.83	16.3	11.41	17.13
(4_1^+)	-	12.69	19.14	13.72	20.64
^{62}Zn(2_1^+)	17(1)	11.02	16.74	12.41	18.71
(4_1^+)	16(1)	9.91	15.08	15.95	24.09
^{64}Zn(2_1^+)	20.1(5)	10.57	16.09	12.46	18.90
(4_1^+)	12.10(5)	12.69	19.36	17.16	26.04
^{66}Zn(2_1^+)	17.5(4)	10.02	15.26	11.90	18.16
(4_1^+)	-	0.47	0.74	14.76	22.43

TABLE III: Occupation number for proton and neutron of fpg orbitals in few y-rast states in ^{60}Zn using jj44b and JUN45 interaction.

$\mathbf{I^\pi}$	$\mathbf{p_{3/2}}$		$\mathbf{f_{5/2}}$		$\mathbf{p_{1/2}}$		$\mathbf{g_{9/2}}$	
	jj44b	JUN45	jj44b	JUN45	jj44b	JUN45	jj44b	JUN45
0_1^+	1.01	1.37	0.52	0.21	0.35	0.34	0.11	0.06
2_1^+	0.90	1.31	0.60	0.28	0.41	0.35	0.08	0.05
4_1^+	0.77	1.08	0.88	0.58	0.26	0.27	0.08	0.05
6_1^+	0.68	0.98	1.03	0.78	0.25	0.20	0.03	0.03
8_1^+	0.84	0.93	1.13	1.05	0.01	0.00	0.018	0.012

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