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Research Article

Studying the nuclear structure for the (^{70}Se, ^{70}Ga, ^{70}Zn) isotopes using NuShellX@MSU code

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Abstract:

The structure of neutron-rich even-even isotopes of A collection of isotopes possessing an identical mass number (A=70), specifically (70Se, 70Ga, 70Zn) has been examined by extensive shell-model simulations. The probabilities B(E2) and B(M1) are calculated using the shell model with NushellX@MSU code, utilizing the effective interaction f5pvh. The findings for excitation energies and reduced transition Probabilities are juxtaposed with the most recent experimental data available. A satisfactory concordance is achieved for all examined isotopes.

1. Introduction

The nuclear shell model was proposed almost 70 years ago by Maria Goeppert Mayer and Hans Jensen, who elucidated the stability of specific nuclei via the notion of "magic numbers" [1]. These investigations have questioned the universality of conventional magic numbers, demonstrating that shell structure can fluctuate considerably with variations in proton and neutron counts[2].Initial implementations of the shell model utilised empirical effective Hamiltonians to characterise nuclear structure, concentrating on nuclei close to stability[1]. Methods such as the Lanczos algorithm and the Monte Carlo shell model have been devised to approach accurate diagonalisation, facilitating the examination of medium- and heavy-mass nuclei[3]. The nucleus constitutes a quantum mechanical configuration, consisting of protons and neutrons[4][5]. The behaviour of these nuclei is affected by the movement of nucleons situated outside the dense central core.made of valence particles[6]. A precise comprehension of the interactions of valence particles is essential for effectively elucidating the characteristics of the nucleus. A variety of nuclear models have clarified the properties of several nuclei[7][8].Among these models, the distinguished nuclear shell model is prominent. This model delineates the energy states, their configurations, and the transitions occurring between them, so offering a substantial representation of nuclear characteristics[9,10].The nuclear shell model has proven highly useful in elucidating nuclear structure; upon identifying an appropriate effective interaction, the shell model may routinely and reliably predict many observables[11]. Principal elements: the interaction among nucleons (N–N interaction) and the spatial configuration designated for valence particles. One can do shell-model calculations utilising either a true N–N interaction within a broad configuration space or a modified effective interaction within a more limited configuration space [12]. Owing to short-range correlations and medium effects, genuine nucleon-nucleon (NN) interactions necessitate renormalisation for application in shell-model computations[13]. This type of engagement is referred to as a "active interaction" [14]. The KB3G [15] and GXPF1A Hamiltonians have yielded predictions for the spectra in this domain, serving as a benchmark for several investigations over the past two decades[16][17]. Both of these represent "universal" Hamiltonians for the p-f model space. Recent findings indicate that a data-driven Hamiltonian for calcium isotopes enhances the representation of all existing data[18]. For light nuclei, there exist multiple "standard" effective interactions, including the Cohen-Kurath

interaction[19]. The isotopes possessing an identical mass number (70Se; Z = 34, 70Ge; Z=32, 70Zn; A=30) encompass three doubly-closed shells with neutron numbers ranging from N = 36 to N = 40, which have been analyzed through advanced shell model calculations utilizing recently developed interaction. Employing(56Ni) as a core within the (f5/2-p p1/2) model space provides a distinctive framework for examining the evolution of shell structure. Isotopic isotopes have garnered new scientific interest to address the question of magicity vs superfluidity about the doubly magic nature of these nuclei[20-24]. Srivastava [25] conducted model computations of the shell for zinc and other isotopes by altering the fpg reaction, adjusting 28 elements of the two-body matrix from the prior reaction. The revised reaction, termed fpg9a, was calibrated for copper isotopes and evaluated for zinc and nickel isotopes. F. Recchia et al. [26] recently examined the level structure of 68Ni using two-neutron ejection and a multiple nucleon transfer process. They juxtapose their experimental findings with shell model calculations employing various contemporary effective interactions. Y. Tsunoda[27] investigated the configurations of neutron-rich exotic many of isotopes using extensive shell model computations utilizing the improved Monte Carlo shell model (MCSM), in which the experimental energy levels are accurately represented using a singular fixed Hamiltonian. This research presents shell model calculations in the f5p-shell region for the even-even (70Se, 70Ga, 70Zn) isotopes, utilizing the contemporary f5pvh effective interaction to evaluate their capacity to replicate experimental results in this mass range [28,29].

2. Shell model

The independent-particle Hamiltonian of an A-particle system can be expressed in terms of two-particle interactions as [16]:

$$H = \sum_{k=1}^{A} T_k + \sum_{k=1}^{A} \sum_{l=k+1}^{A} W(\vec{r}_k, \vec{r}_l) \quad (1)$$

where $W(\overrightarrow{rk}, \overrightarrow{rl}\}$ \) represents the two-body interaction between the k^{th} and l^{th} nucleons. By selecting an average potential $U(r_k)$, the Hamiltonian is expressed as [16].

$$.H = \sum_{k=1}^{A}[T_k + U(r_k)] + \sum_{k=1}^{A}\sum_{l=k+1}^{A} W(\overrightarrow{r_k}, \overrightarrow{r_l}) - \sum_{k=1}^{A} U(r_k) \quad (2)$$

The initial term corresponds to the independent-particle Hamiltonian, whereas the subsequent second and third terms address the divergence from independent particle motion, referred to as the residual interaction. By partitioning the summations into core and valence components, equation (2) can be reformulated [20].

$$H = H_{core} + H_1 + H_2 + V(\overrightarrow{r_1}, \overrightarrow{r_2}) \quad (3)$$

In the aforementioned equation, H_{core} encompasses all interactions among the nucleons constituting the core, H_1 and H_2 represent the single-particle contributions from particles 1 and 2, respectively, while $V(\overrightarrow{r_1},\overrightarrow{r_2})$ denotes the residual interaction that characterizes all interactions between particles 1 and 2, as well as any interactions with core nucleons. Substituting this variant of the Hamiltonian into the Schrödinger equation produces a corresponding expression for the energy [16].

$$E = E_{core} + E_1 + E_2 + \langle \Phi_{J,\tau} | V(\overrightarrow{r_1}, \overrightarrow{r_2}) | \Phi_{J,\tau} \rangle \quad (4)$$

Here, E_{core} represents the binding energy of the core nucleus, while E_1 and E_2 denote the single-particle energies of the orbitals external to the core. Additionally, $\langle \Phi_{J,\tau} | V(\overrightarrow{r_1}, \overrightarrow{r_2}) | \Phi_{J,\tau} \rangle$ signifies the residual interaction that must be theoretically specified. It is essential to recognize that the energy provided by equation (4) pertains exclusively to pure arrangements. In principle, every adjacent state possessing identical total angular momentum J and total isospin τ will undergo mixing. The mixed eigenstates are represented by linear combinations of the unperturbed wave functions [1,16].

$$(\psi_{J,\tau})_p = \sum_{k=1}^{g} a_{kp} (\Phi_{J,\tau})_p \quad (5)$$

where g represents the number of mixed configurations, and the label p takes values from 1 to g. The coefficients a_{kp} satisfy the condition [4].

$$\sum_{k=1}^{g} |a_{kp}|^2 = 1 \quad (6)$$

Substituting equation (5) into the Schrödinger equation yields,

$$H(\psi_{J,\tau})_p = E_p(\psi_{J,\tau})_p \quad (7)$$

resulting in a system of linear equations [20].

3. Results and Discussions

3.1Excitation Energies

The core is represented by (56Ni) for all studied isotopes, with valence nucleons allocated in the

(1f5/2, 2p3/2, and 2p1/2) valence space, utilizing the f5pvh effective interaction through the shell model NushellX@MSU code. The computed energy levels for (70Se, 70Ga, 70Zn) isotopes are compared utilizing f5pvh effective interaction alongside the most recent experimental data. The theoretical calculations encompass fourteen nucleons external to the closed core of the (70Se, 70Ga, 70Zn) nucleus, consistent with the anticipated conclusions presented in The tables (1,2 and 3) regarding total angular momentum and symmetry

1. 70Se

Table (1) delineates a comparison between the experimental outcomes for the 70Se isotope utilizing the f5pvh interaction and the presently accessible theoretical conclusions (No Title13. "1-Jul-2016 ENSDF insertion: 2016-09 Publication: Nuclear Data Sheets 136, 1 (2016) 10.1016/j.nds.2016.08.001" n.d.).

Table 1. *Excitation energy predictions for the 70Se isotope using f5pvh interaction and observed experimental energies comparison*

Theoretical values of E(MeV)		**Experimental values**	
J^+	f5pvh	E(MeV)	J
0_1	0	0.0	0^+
2_1	0.873	0.944	2^+
0_2	1.534	-------	-------
2_2	1.591	1.599	2^+
2_3	2.019	2.010	(0^+)
4_1	2.083	2.038	4^+
3_1	2.196	-------	-------
2_4	2.245	-------	-------
2_5	2.445	-------	-------
4_2	2.473	2.382	4^+
1_1	2.566	2.553	-------
3_2	2.586	2.518	$4^{(-)}$
0_3	2.593	-------	-------
4_3	2.691	-------	-------
2_6	2.711	-------	-------
0_4	2.713	-------	-------
1_2	2.766	-------	-------
4_4	2.876	-------	-------
2_7	2.895	-------	-------
4_5	2.917	-------	-------
3_3	2.928	-------	-------
3_4	2.984	-------	-------
4_6	3.051	-------	-------
1_3	3.074	-------	-------
3_5	3.126	3.139	-------
4_7	3.163	-------	-------
2_8	3.186	-------	-------
2_9	3.205	-------	-------
3_6	3.289	-------	-------
5_1	3.299	3.218	(6^+)
2_{10}	3.315	-------	-------
1_4	3.316	-------	-------
5_2	3.335	3.356	-------
0_5	3.417	-------	-------
1_5	3.418	-------	-------
3_7	3.465	-------	-------
4_8	3.518	3.524	(5^-)
4_9	3.566	-------	-------
0_6	3.569	-------	-------
6_1	3.621	3.788	(6^-)
4_{10}	3.626	-------	-------
1_6	3.645	3.644	-------
3_8	3.679	-------	-------
1_7	3.733	-------	-------
3_9	3.802	-------	-------
1_8	3.813	-------	-------
5_3	3.883	-------	-------
3_{10}	3.887	-------	-------
6_2	3.893	-------	-------
1_9	3.937	-------	-------
0_7	3.949	-------	-------
5_4	4.033	-------	-------
1_{10}	4.071	-------	-------
6_3	4.112	-------	-------
6_4	4.162	-------	-------
0_8	4.191	-------	-------
0_9	4.217	-------	-------
5_5	4.234	-------	-------
5_6	4.261	-------	-------
0_{10}	4.328	4.324	-------
5_7	4.347	-------	-------
5_8	4.374	-------	-------
6_5	4.398	4.410	-------
6_6	4.58	-------	-------
5_9	4.628	-------	-------
5_{10}	4.663	-------	-------
6_7	4.709	-------	-------
6_8	4.785	-------	-------
7_1	4.887	4.896	(9^-)
6_9	5.131	-------	-------
7_2	5.21	5.209	(9^-)
6_{10}	5.233	-------	-------
7_3	5.373	-------	-------
7_4	5.44	-------	-------
8_1	5.532	-------	-------
8_2	5.571	-------	-------
7_5	5.682	5.693	(10^+)
7_6	5.844	-------	-------
7_7	5.905	-------	-------
8_3	6.01	6.017	-------
7_8	6.039	-------	-------
7_9	6.094	-------	-------
8_4	6.155	-------	-------
8_5	6.174	-------	-------
7_{10}	6.177	-------	-------
8_6	6.362	-------	-------
8_7	6.467	-------	-------
8_8	6.56	6.510	(12^+)
8_9	6.68	6.602	(12^+)
8_{10}	6.812	-------	-------
9_1	6.977	6.956	(12^+)
9_2	7.079	-------	-------
9_3	7.203	-------	-------
9_4	7.331	7.305	(13^-)
10_1	7.421	-------	-------
9_5	7.551	7.554	(13^-)
9_6	7.688	-------	-------
9_7	7.751	-------	-------
10_2	7.904	7.940	(14^+)
9_8	7.912	-------	-------
10_3	7.986	-------	-------
9_9	8.025	8.017	(15^-)
9_{10}	8.111	-------	-------

10_4	8.141	-------	-------
10_5	8.19	-------	-------
10_6	8.391	8.349	-------
10_7	8.67	-------	-------
10_8	8.868	-------	-------
10_9	8.972	-------	-------
10_{10}	9.072	-------	-------
11_1	9.361	-------	-------
11_2	9.386	-------	-------
11_3	9.494	4.496	(16^+)
12_1	9.677	-------	-------
11_4	10.037	-------	-------
11_5	10.204	-------	-------
11_6	10.354	-------	-------
11_7	10.425	-------	-------
11_8	10.557	-------	-------
12_2	10.643	10.646	(18^+)
11_9	10.717	-------	-------
11_{10}	10.759	-------	-------
12_3	10.875	-------	-------
12_4	11.061	-------	-------
12_5	11.761	-------	-------
12_6	12.094	-------	-------
12_7	12.145	-------	-------
12_8	12.323	-------	-------
12_9	12.491	-------	-------
13_1	12.502	-------	-------
12_{10}	12.615	-------	-------
13_2	12.965	-------	-------
13_3	14.379	-------	-------

By comparing the experimental data for this isotope in the table above with our theoretical findings using the f5pvh interaction, the following can be observed: A comparison with the practical numbers available indicated that the ground state parity and total angular momentum of the 0+ level were equal.

The angular momentum and parity of practical energy was determined to be (2.553, 3.139, 3.356, 3.644, 4.324, 4.410, 6.017, 8.349, 2.010, 3.218, 5.693, 6.510, 6.602, 6.956, 7.940, 4.496, 10.646) MeV, corresponding to positive parity angular momentum value of 1, 5, 1, 0, 6, 8, 2, 6, 10, 12, 12, 12,14, 16 and 18, respectively. And (3.524, 3.788, 4.896, 5.209, 8.017, 2.518) MeV with angular momentum 4, 6, 7, 7, 9, 9, 9, 3 but negative parity. This reflects the degree of alignment between the practical value and our theoretical value.

By comparing the theoretically computed energies(0.873MeV; 2^+),) 1.591MeV;2^+),) 2.083;4^+) and) 2.473MeV;4^+) with the available experimental data, we were able to get good agreement for the angular momentums.

According to our calculations, the maximum experimental energy value is 20.246MeV, and the greater predicted energy is theoretically 14.379MeV.

Through the theoretical calculations, we have (103) state with the total angular momentum & parity that have not symmetry by another practical value thus far.

2. 70Ga

Table (3) delineates a comparison between the experimental outcomes (No Title13. "1-Jul-2016 ENSDF insertion: 2016-09 Publication: Nuclear Data Sheets 136, 1 (2016) 10.1016/j.nds.2016.08.001" n.d.)for the 70Ga isotope utilizing the f5pvh interaction and the presently accessible theoretical conclusions .

Table 3. *Excitation energy predictions for the 70Ga isotope using f5pvh interaction and observed experimental energies comparison (No Title13. "1-Jul-2016 ENSDF insertion: 2016-09 Publication: Nuclear Data Sheets 136, 1 (2016) 10.1016/j.nds.2016.08.001" n.d.)*

Theoretical values		**Experimental values**	
J^+	E (MeV)	E (MeV)	J^π
1_1	0.000	0.0	1^+
2_1	0.153	-------	-------
4_1	0.276	-------	-------
3_1	0.404	-------	-------
3_2	0.447	-------	-------
2_2	0.465	0.508	2^+
1_2	0.594	0.651	$1^+, 2^+$
2_3	0.613	0.690	2^-
4_2	0.679	0.879	4^-
1_3	0.697	-------	-------
0_1	0.738	-------	-------
3_3	0.799	-------	-------
1_4	0.818	0.901	$1^+, 2^+, 3^+$
2_4	0.888	0.995	2^+
0_2	0.989	1.002	-------
2_5	1.031	1.014	$1^+, 2^+, 3^+$
3_4	1.199	1.023	$2^+, 3^+$
5_1	1.226	1.180	5
3_5	1.279	1.253	$3^-, 4^-$
2_6	1.281	1.258	1^+ to 4^+
1_5	1.349	1.312	$1^+, 2^+$
2_7	1.368	1.359	2^+
3_6	1.385	-------	-------
2_8	1.400	1.445	$1^+, 2^+$
0_3	1.420	-------	-------

4_3	1.431	-------	-------
1_6	1.470	1.456	1^+, 2^+
4_4	1.543	1.523	-------
3_7	1.587	-------	-------
2_9	1.596	1.598	-------
1_7	1.630	1.633	1, 2, 3
2_{10}	1.682	1.691	-------
5_2	1.722	1.725	-------
3_8	1.736	1.735	-------
6_1	1.767	-------	-------
4_5	1.812	1.807	-------
5_3	1.813	1.824	-------
1_8	1.880	1.846	-------
4_6	1.882	1.865	-------
0_4	1.888	1.877	-------
3_9	1.911	1.905	+
1_9	1.965	1.937	+
3_{10}	1.979	1.970	+
4_7	2.043	2.026	-------
1_{10}	2.151	2.142	-------
5_4	2.190	2.189	-------
4_8	2.301	2.300	+
4_9	2.331	2.351	-------
6_2	2.462	2.464	-------
5_5	2.495	2.477	-------
4_{10}	2.525	2.520	-
7_1	2.638	2.601	(8)
5_6	2.709	2.698	-------
0_5	2.748	2.726	-------
5_7	2.821	2.886	(9)
0_6	2.939	-------	-------
6_3	2.954	-------	-------
5_8	2.984	-------	-------
5_9	3.089	-------	-------
6_4	3.096	-------	-------
5_{10}	3.221	-------	-------
6_5	3.275	-------	-------
0_7	3.414	-------	-------
6_6	3.733	-------	-------
7_2	3.739	-------	-------
0_8	3.767	-------	-------
0_9	3.809	-------	-------
0_{10}	4.111	-------	-------
6_7	4.193	-------	-------
7_3	4.265	-------	-------
8_1	4.292	-------	-------
6_8	4.308	-------	-------
6_9	4.489	-------	-------
7_4	4.706	-------	-------
6_{10}	4.743	-------	-------
7_5	4.833	-------	-------
7_6	6.347	-------	-------
7_7	6.593	-------	-------

By comparing the experimental data for this isotope in the table above with our theoretical findings using the f5pvh interaction, the following can be observed:

- A comparison with the available empirical data revealed that the ground state parity and total angular momentum of the 1+ level were identical.
- The angular momentum and parity of practical energies were determined to be (1.002Mev, 0^+) ,(1.523Mev, 4^+),(1.598Mev, 2^+),(1.691Mev,3^+), (1.725Mev, 5^+),(1.735Mev,3^+), (1.807Mev, 4^+), (1.824Mev, 5^+),(1.846Mev, 1^+), (1.865Mev, 4^+), (1.877Mev, 0^+),(2.026Mev, 4^+) ,(2.142Mev, 〚 1〛 ^+), (2.189Mev, 5^+),(2.351 Mev, 4^+), (2.464Mev, 6^+) ,(2.477Mev, 5^+),(2.726Mev, 5^+)and(2.698Mev,0^+), corresponding to positive angular momentum. This reflects the degree of alignment between the practical value.
- By juxtaposing the theoretically calculated energies(0.465Mev, 2^+) ,(0.594Mev,1^+), (0.818Mev, 〚 1〛 ^+),(0.888Mev, 2^+),(1.031Mev, 2^+),(1.199Mev,3^+),(1.281Mev, 2^+),(1.349Mev, 1^+),(1.400Mev, 2^+) and (1.470Mev, 1^+) with the existing experimental data, we achieved substantial concordance for the angular momentums and parity.
- This analysis anticipated that the total angular momentums for the practical energies of (1.905,

1.937, 1970, 2.300)MeV are consistent with parity matching.

- According to our calculations, the maximum experimental energy value is 8.349MeV, and the greater predicted energy is theoretically 14.379MeV.
- The total angular momentum was verified, and the parity was anticipated to be positive rather than negative at the experimental energies of 0.690, 0.879, and 1.253 MeV, corresponding to angular momenta of 2+, 4+, and 3+, respectively.
- We anticipate a total angular momentum for the indeterminate practical energies(2.601,2.886) MeV, corresponding to angular momenta of 7, 5 rather than 8,9 and a positive parity was determined for them.
- By juxtaposing the theoretically calculated energies with the existing experimental data, we achieved substantial concordance for the angular momentums for (1.633 MeV;1) and and symmetry of practical energies were determined positive.
- Through the theoretical calculations, we have (38) state with the total angular momentum and parity that have not symmetry by another practical value thus far.

3. 70Zn

Table 2. *Excitation energy predictions for the 70Zn isotope using f5pvh interaction and observed experimental energies comparison*

Theoretical values		**Experimental values**	
J^+	**E (MeV)**	**E (MeV)**	**J**
0_1	0.000	0.0	0^+
2_1	1.283	0.884	2^+
4_1	2.652	2.693	4^+
2_2	2.723	2.805	-------
1_1	3.043	2.949	1^+
0_2	3.339	3.328	(0^+)
2_3	3.356	3.634	2^+
3_1	3.411	3.419	(0^+)
1_2	3.688	3.750	$(0^-, 1^-, 2^-)$
2_4	4.294	4.291	2^+
2_5	4.576	4.588	$(5, 6, 7^-)$
3_2	4.612	4.367	3^+
0_3	4.674	-------	-------
4_2	4.685	4.444	$3^+, 4^+, 5^+$

By comparing the experimental data for this isotope in the table above with our theoretical findings using the f5pvh interaction, the following can be observed:

- A comparison with the available empirical data demonstrated that the ground state parity and total angular momentum of the 0+ level were identical.
- The angular momentum and parity of practical energy was determined to be (2.805,3.419)MeV, associated with angular momentum state 2^+ and 3^+,and(4.588) MeV with angular momentum 2 but negative parity. reflects the degree of alignment between the practical value and our theoretical value.
- By juxtaposing the theoretically calculated energies (1.283MeV; 2^+),(2.652MeV; 4^+),(3.043MeV; 1^+),(3.356MeV;2^+),(4.294MeV; 2^+),(4.612MeV; 3^+) and (4.685MeV;4^+) with the existing experimental data, we achieved a commendable concordance for the angular momenta.
- The parity and total angular momentum of the experimentally un confirmed energies (3.328) MeV, corresponding to positive angular momentum value of 2, And (3.750) MeV with angular momentum 2 but negative parity. This, are confirmed
- According to our calculations, the maximum experimental energy value is 6.116MeV, and the greater predicted energy is theoretically 4.685MeV.

3.2 Electromagnetic transition probability B(E2) and B(M1)

It is possible to think of gamma-rays as a type of electromagnetic radiation in which the electric field changes, causing the magnetic field to change as well. Radiation can be created by a fluctuating external magnetic field caused by an oscillating charge, or it can be produced by a changing magnetic field caused by a change in current or magnetic moment.

1. 70Se

We observed a reasonable agreement between the available experimental data and the theoretical data for the electrical transitions B(E2)2_1^+→0_1^+ , B(E) 2_2^+→0_1^+, B(E) 2_2^+→2_1^+, B(E) 4_1^+→2_1^+ and B(E) 4_1^+→2_2^+ for using the (f5pvh) interaction. We observed a reasonable agreement between the available experimental data and the theoretical data for the electrical transitions B(M1) 2_2^+→2_1^+ for using the (f5pvh) interaction. Our calculations revealed new transitions that had no experimental values before. A satisfactory agreement was observed for the transitions B(M1) 2_2^+→2_1^+ when we compared some of our findings for the magnetic transitions of the interaction (f5pvh) with the experimental study (No Title13. "1-Jul-2016 ENSDF insertion: 2016-09 Publication: Nuclear Data Sheets 136, 1 (2016) 10.1016/j.nds.2016.08.001" n.d.).

Table 4. *Comparison of the B(E2)and B(M1) results by using) f5pvh (interaction in units e2fm4 and μ_N^2 respectively for the 70Se isotope with the experimental data*

J_i^+	→	J_f	B(M1) (μ_N^2)		B(E2) e^2fm^4	
			Theory	Exp.	Theory	Exp.
2_1	→	0_1^+	0.0000	------	316.5000	17.9
0_2	→	2_1^+	0.0000	------	85.6000	------
2_2	→	0_1^+	0.0000	------	4.3210	0.19
2_2	→	2_1^+	0.0024	0.009	266.3000	33
2_2	→	0_2^+	0.0000	------	142.0000	------
2_3	→	0_1^+	0.0000	------	8.3950	------
2_3	→	2_1^+	0.0366	------	27.7100	------
2_3	→	0_2^+	0.0000	------	161.8000	------
2_3	→	2_2^+	0.1371	------	3.3420	------
4_1	→	2_1^+	0.0000	------	438.2000	21.5
4_1	→	2_2^+	0.0000	------	7.4550	17
4_1	→	2_3^+	0.0000	------	9.9710	------

2. 70Zn

We observed a reasonable agreement between the available experimental data and the theoretical data for the electrical transitions B(E2) 2_1^+→0_1^+, B(E2) 4_1^+→2_1^+, B(E2) 2_2^+→0_1^+, B(E2) 2_2^+→2_1^+, B(E2) 1_1^+→2_2^+ and B(E2) 0_2^+→ 2_1^+ for using the (f5pvh) interaction. Our calculations revealed new transitions that had no experimental values before.

A satisfactory agreement was observed for the transitions B(M1) 2_2^+→2_1^+and B(M1) 1_1^+→2_2^+ when we compared some of our findings for the magnetic transitions of the interaction (f5pvh) with the experimental study (No Title13. "1-Jul-2016 ENSDF insertion: 2016-09 Publication: Nuclear Data Sheets 136, 1 (2016) 10.1016/j.nds.2016.08.001" n.d.)

Table 5. *Comparison of the B(E2)and B(M1) results by using) f5pvh (interaction in units e2fm4 and μ_N^2 respectively for the 70Zn isotope with the experimental data*

J_i^+	→	J_f	B(M1) (μ_N^2)		B(E2) e^2fm^4	
			Theory	Exp.	Theory	Exp.
2_1	→	0_1^+	0.0000	------	114.6000	286.1763
4_1	→	2_1^+	0.0000	------	79.4500	325.5898
2_2	→	0_1^+	0.0000	------	9.8500	10.2818
2_2	→	2_1^+	0.4488	0.0170	38.4200	171.3630
2_2	→	4_1^+	0.0000	------	72.8900	------
1_1	→	0_1^+	0.0872	------	0.0000	------
1_1	→	2_1^+	0.0036	------	2.1860	------
1_1	→	2_2^+	3.5930	0.0039	2.9340	188.4993
0_2	→	2_1^+	0.0000	------	0.1468	639.1841

3. 70Ga

We observed a reasonable agreement between the available experimental data and the theoretical data for the electrical transitions B(E2) 3_1^+→2_1^+ for using the (f5pvh) interaction. Our calculations revealed new transitions that had no experimental values before. A satisfactory agreement was observed for the transitions B(M1) 3_1^+→2_1^+ when we compared some of our findings for the magnetic transitions of the interaction (f5pvh) with the experimental study (No Title13. "1-Jul-2016 ENSDF insertion: 2016-09 Publication: Nuclear Data Sheets 136, 1 (2016) 10.1016/j.nds.2016.08.001" n.d.).

Table 2. *Comparison of the B(E2)and B(M1) results by using) f5pvh (interaction in units e2fm4 and μ_N^2 respectively for the 70Ga isotope with the experimental data*

J_i^+	→	J_f	B(M1) (μ_N^2)		B(E2) e^2fm^4	
			Theory	Exp.	Theory	Exp.

2_1	→	1_1	0.0166	------	25.860	------
4_1	→	2_1	0.0000	------	33.7600	------
3_1	→	1_1	0.0000	------	2.0350	------
3_1	→	2_1	0.4340	1.2530	0.0007	0.0027
3_1	→	4_1	0.8921	------	19.0200	------
3_2	→	1_1	0.0000	------	84.6300	------
3_2	→	2_1	1.1970	------	15.7200	------
3_2	→	4_1	0.1289	------	4.5750	------
3_2	→	3_1	0.3053	------	39.0800	------

4. Conclusions

This study conducted extensive shell model computations for neutron-rich, isotopes of (Se, Ga, Zn) for A=70. The current work demonstrated that the energy levels and electromagnetic transition probability were computed using the interaction f5pvh and the results were shown to be in reasonable accord with the existing experimental data. Numerous energy stats have been confirmed using the interaction and additional energy levels have been acquired in our computations. The B(E2) and B(M1) values also showed some degree of compatibility with the experimental results.

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- **Ethical approval:** The conducted research is not related to either human or animal use.
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