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Binding Energy and Energy Level with B(E2; 0–2) of Neutron-Rich 60-66Fe Isotopes using NuShellX

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Abstract

Binding energy of the ground state, energy levels and B(E2; $0_1^+ \rightarrow 2_1^+$ *) values for even-even Fe isotopes with proton number Z=26 and neutron numbers (n) between 34 and 40 have been calculated through shell model calculations using the shell model code NuShellX for Windows by employing harmonic oscillator (HO) model space and the GXPF1A, KB3G and FPD6 interactions. The binding energies calculations are reasonably consistent with the available experimental data. The predicted low-lying levels (energies, spins and parities) are in good agreement with newly experimental data, and by employed FPD6 for 60Fe nucleus, GXPF1A for 62Fe nucleus and KB3G for 64,66Fe nuclei. Furthermore, B(E2;* $0_1^+ \rightarrow 2_1^+$ *) values are in good agreements with available experimental data.*

Keywords: *Shell model, neutron-rich, Binding energy, energy levels, B(E2) value*

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INTRODUCTION

In case of the *fp* shell, the nuclear physics community is focus and attention in the neutron rich nuclei at present time. Unstable nuclei in *fp* region [1] led to many new phenomenon such as appearance of new magic numbers and disappearance of well-established ones, softening of core at neutrons number (N=28), interplay of collective and single particle properties etc. The shell model has been well described of the nuclei in the *fp* shell by using several model spaces and two-body interactions, the most remarkable work of [2–8] because of special interest in astrophysics such as the electron capture rate in supernovae explosion. The experimental and theoretical information available on neutron rich species are relatively limited. For example, previous studies of low-lying states for nuclei in the *fp* region are scattered and incomplete whereas Lunardi et al. [9] used large scale shell model calculations with an effective interaction '*fpg*' described in [10] to interpret the results of the experiments on $^{61-66}$Fe isotopes. Shell model calculations in the lower *fp* shell region had been performed for the isovector T=1 positive parity states by employing the effective interactions GXPF1, FPD6 and KB3G [11]. P.C. Srivastava and I. Mehrotra [1] used large scale shell model with a newly effective interaction GXPF1A in full *fp* space without truncation with code ANTOINE to interpret the experimental data of Legnaro National Laboratories on neutron rich even isotopes of $^{62-66}$Fe.

The aim of present work is to apply the shell model by using harmonic oscillator model space (HO) with effective interactions GXPF1A, KB3G and FPD6 in the *fp* shell region to calculate binding energy, energy levels and B (E2) value for Fe isotopes. I believe that these isotopes can be well described by the nuclear shell model. Furthermore, the necessary nuclear data from this work is important in the nuclear astrophysicists.

SOFTWARE PROGRAM AND SHELL MODEL

Binding energy, energy level and B(E2) values calculations have been carried out using the code NuShellX for windows[12–14] for neutron rich even Fe isotopes with A=60-66 treating ^{48}Ca as inert core. The m-scheme Slater determinant basis and technique wave functions with good angular momentum *J* and isospin *T* were constructed in this code. The

Harmonic oscillator model spaces (P1F7/2, N2P3/2, N1F5/2 and N2P1/2) with different effective interactions are employed for the calculations of binding energy, energy level and B(E2) values. The three effective interactions are GXPF1A [15], KB3G [16] and FPD6 [17].

Binding Energy

The nuclear astrophysicists are interested in the binding energies, because it is important to determine Q-values of proton captures reactions and beta decays.

The experimental [18] and theoretical binding energies and the calculations of the deviation from experimental binding energies, δB = B(EXP.) – B(Cal.)are shown in Figure 1. In this figure the solid symbols (circle, square and triangle) represent the experimental data; present work (P.W.) and deviation of P.W. from the experimental data, respectively. The figure shows that the calculations results were closed from the experimental binding energies. Furthermore, the deviation decreases with neutron numbers increase and the best value is show at ^{66}Fe isotope.

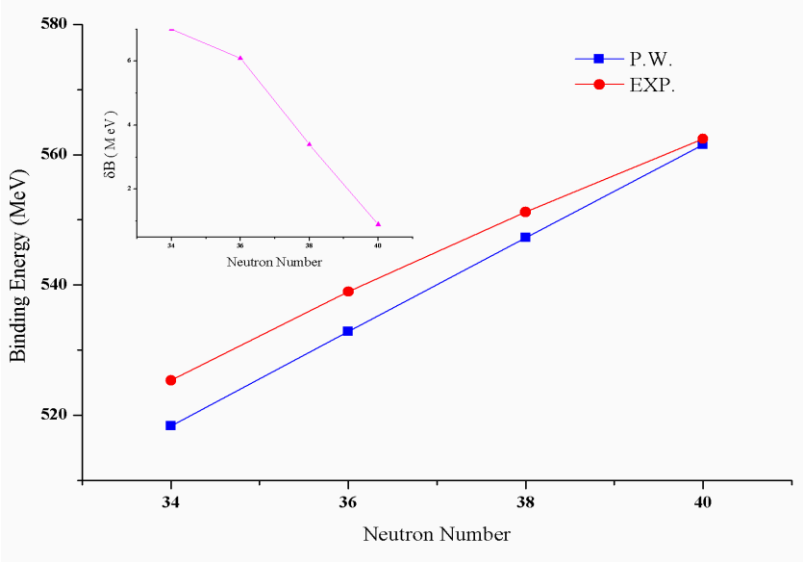

Fig. 1: *Calculated Binding Energies Compared with the Experimental Data [18].*

Energy Levels

The calculations of the energy levels with different effective interactions GXPF1A, KB3G and FPD6 for $^{60\text{-}66}$Fe isotopes are shown in Figure 2. The calculated values from GXPF1A interaction are plotted on the left, the experimental data and the KB3G and FPD6 values on the right, respectively. The bracket '( )' represents the spin and/or parity of the corresponding states which are not well established experimentally. The experimental data for all nuclei interest were taken from [19], in addition [20] for ^{66}Fe. Table 1 shows the values of the root mean square deviation (RMSD) [21] between theoretical energy levels and the experimental; $\mathrm{RMSD}=[\frac{1}{m}\sum E_{Cal.}-E_{Exp.})^2]^{1/2}$, where m is the number of levels. Figure 2 and Table 1 show that our calculations are in good agreement with the experimental data for ^{62}Fe, ^{64}Fe and ^{66}Fe and ^{60}Fe, respectively. The first 2^+ excited state energy levels E (2^+) as a function of neutrons number are shown in Figure 3. The sign of the collectivity increases with the drop in the excitation energy which is clear from the experimental value [22] of the first 2^+ decrease with neutron numbers increase.

Table 1: *The RMSD between Experimental and Calculated Energy Levels.*

A	RMSD (MeV)		
	GXPF1A	KB3G	FPD6
60	0.371	0.587	0.176
62	0.113	0.234	0.554
64	0.265	0.162	0.757
66	0.398	0.159	0.540

B(E2) Values

Transition strengths calculated (assuming pure E2 transition) by using the harmonic oscillator potential (HO, X) for each nuclei. The B(E2) values for $0_1^+ \rightarrow 2_1^+$ transition are plotted in Figure 4. This figure shows that the experimental B(E2) values are reproduced satisfactorily. In addition, the calculated values deviate significantly from experimental data, even showing an opposite trend with experimental data because the our calculations with GXPF1A, KB3G and FPD6 interactions in HO model space failed in the 2_1^+ energy level for some isotopes. The B(E2) value decreases when the energy level is higher than experimental data.

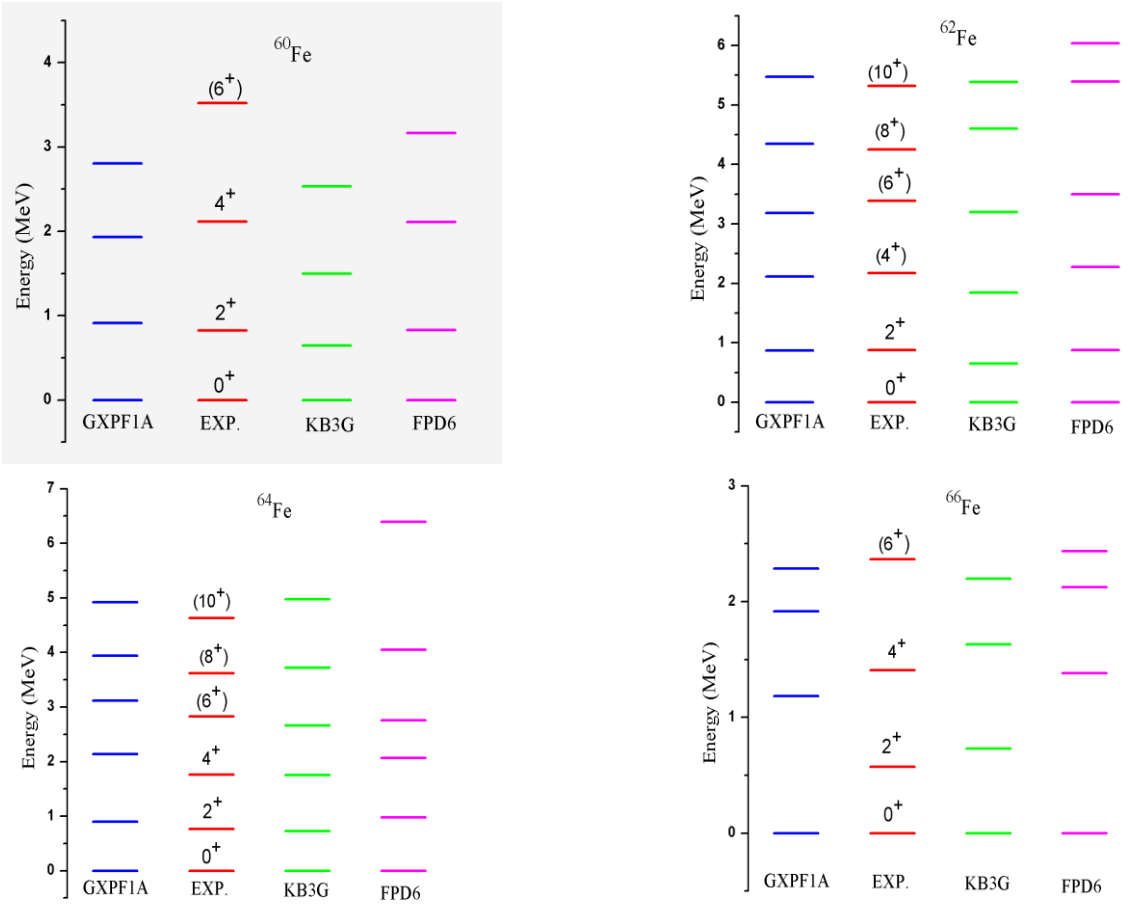

Fig. 2: *Comparison between the Calculated Energy Levels and the Experimental Data [19, 20] for of $^{60\text{-}66}$Fe Isotopes.*

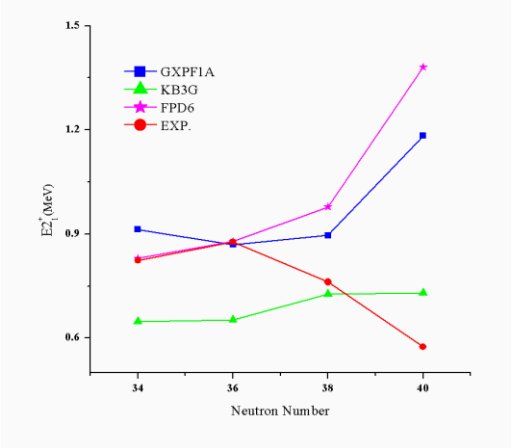

Fig. 3: *First 2^+ Energy Levels Plotted with Neutron Number.*

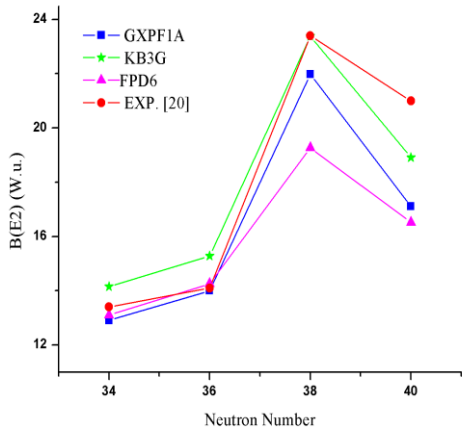

Fig. 4: *B(E2; 0^+--- 2^+) Values Plotted with Neutron Number.*

CONCLUSIONS

The binding energy of the ground state, low excited energy levels and the B(E2) value for $0_1^+ \rightarrow 2_1^+$ transition, for neutron rich even isotopes of Fe with A=60,62,64 and 66 in the HO model space have been calculated through the shell model calculations using the code NuShellX for Windows by employing three effective interactions. The GXPF1A, KB3G and FPD6 effective interactions were employed with the HO model space, which comprised of (P1F7/2, N2P3/2, N1F5/2 and N2P1/2) for the calculations. The binding energies calculations are reasonably consistent with the available experimental data. The predicted low-lying levels (energies, spins and parities) are in good agreement with newly experimental data, by employing FPD6 for ^{60}Fe nucleus, GXPF1A for ^{62}Fe nucleus and KB3G for ^{64,66}Fe nuclei. The calculated results of B (E2) value for $0_1^+ \rightarrow 2_1^+$ transition are in good agreement with the experimental data.

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