Large-Scale Shell-Model Calculations for Even–Odd $^{61}$–$^{65}$Fe Isotopes*

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Abstract—Large-scale shell-model calculations have been performed to calculate the negative-parity states of even–odd $^{61}$–$^{65}$Fe isotopes. The results are compared with the recent experimental data reported at Legnaro National Laboratories and also with earlier calculations with $fp$ interaction in a truncated configuration space. It is observed that negative parity states of $^{61}$Fe can be well reproduced with GXPF1A interaction in full $fp$ space without truncation. For $^{63}$Fe the correct ordering of levels is not reproduced. The structure of the wave function for the ground state and first excited state suggests that the ordering of the single-particle energy levels gets modified due to monopole correction.

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1. INTRODUCTION

With the development of radioactive ion beam facilities, exotic nuclei attract much attention due to the appearance of new phenomena such as of halo, skin, and new magic number. On the other hand, the recent developments in computational facilities, as well as numerical methods, enable us to study all the states of the $fp$ shell nuclei without truncation. However, it is still out of reach to diagonalize full $fpgh_{9/2}$ shell without truncation. This is also the region where the shell model is most successful in describing the nuclear structure properties. The region of nuclear chart between Ca and Ni also has astrophysical applications.

At the Legnaro National Laboratories neutron-rich Fe isotopes from $A = 61–66$ were recently populated by Lunardi et al. [1] through multineutron transfer reaction by bombarding a $^{238}$U target with 400–MeV $^{64}$Ni beam. The identification of $\gamma$-rays belonging to each nucleus was carried out with high precision by coupling the clover detector of Euroball (CLARA) to PRISMA magnetic spectrometer. This experiment has provided data on level structure of neutron-rich Fe isotopes from $A = 61$ to 66. Lunardi et al. have interpreted the results of their experiments on $^{61–66}$Fe isotopes by performing large-scale shell-model calculations with an effective interaction $fpg$ described in [2]. In the present work we have performed large-scale shell-model calculations on neutron-rich $^{61–65}$Fe odd isotopes with recently-developed GXPF1A interaction suitable for unstable nuclei in $fp$ shell with $N \geq 35$ [3]. Similar calculations for even isotopes of $^{62–66}$Fe also were performed by us and have been reported in the literature [4]. The calculations have been carried out in valence space of full $fp$ shell consisting of $0f_{7/2}$, $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$ orbitals and treating $^{40}$Ca as the inert core. No restriction has been put on the number of particles which can be excited to higher level. Our calculations differ from that of Lunardi et al. in two ways: (i) we have treated $^{40}$Ca as the inert core whereas Lunardi et al. have considered $^{48}$Ca as inert core, (ii) we have considered full valence space comprising of $0f_{7/2}$, $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$ orbitals for both protons and neutrons, whereas in the work of Lunardi et al. an inert core of $^{48}$Ca is considered and the model space comprises of the $0f_{7/2}$, $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$ active proton orbitals and $0f_{7/2}$, $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$, $0g_{9/2}$ neutron orbitals with eight $f_{7/2}$ frozen neutrons. In $fpg$ Lunardi et al. used truncation by allowing up to a total of five particle excitations from the $f_{7/2}$ orbital to the upper $fp$ orbitals for protons and from the upper neutron $fp$ orbitals to the $g_{9/2}$ orbital. Thus, apart from testing the suitability of GXPF1A interaction in explaining the experimental data, a comparison of our results with that of Lunardi et al. results will also throw light on the role of intruder $g_{9/2}$ orbital, appropriate choice of core, and the effect of truncation on the particles to be excited.

2. DETAILS OF CALCULATION

The aim of the present paper is to test the suitability of GXPF1A interaction towards the end of $fp$
The single-particle energies for model space are obtained from various viewpoints such as binding energy data out of 87 stable nuclei. These elements by iterative fitting calculations about 699 experimental energy data and also with the results obtained with fpg interaction in a truncated configuration space. In the case of $^{61}$Fe the calculated energy difference between $1/2^-$ and $3/2^-$ is only of the order of 86 keV. If this difference being less than 100 keV is neglected, the ordering of the levels is correctly reproduced. For fpg interaction also calculated $1/2^-$ level lies 36 keV below $3/2^-$ level and has been suppressed in the Fig. 1. The calculated $7/2^-$ state is at 1074 keV above the ground-state compared to the experimental value of 959 keV. In the case of $^{63}$Fe measured ground-state spin and parity is $5/2^-$ and the first excited $3/2^-$ state lies above 356 keV. GXPF1A interaction also calculated $1/2^-$ level lies 36 keV below $3/2^-$ level and has been suppressed in the Fig. 1. The calculated $7/2^-$ state is at 1074 keV above the ground-state compared to the experimental value of 959 keV. In the case of $^{65}$Fe measured ground-state spin and parity is $5/2^-$ and the first excited $3/2^-$ state lies above 356 keV. GXPF1A interaction also calculated $1/2^-$ level lies 36 keV below $3/2^-$ level and has been suppressed in the Fig. 1. The calculated $7/2^-$ state is at 1074 keV above the ground-state compared to the experimental value of 959 keV. In the case of $^{65}$Fe measured ground-state spin and parity is $5/2^-$ and the first excited $3/2^-$ state lies above 356 keV.

Fig. 1. Calculated energy levels of $^{61}$Fe with GXPF1A interaction compared with the experimental data and the previous theoretical work using fpg interaction with truncation from [1]. Energy is in keV.

Fig. 2. The same as in Fig. 1, but for $^{63}$Fe.

Fig. 3. The same as in Fig. 1, but for $^{65}$Fe.