Revisiting the high-spin states in ^{54}Mn reveals its new structure

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Introduction

^{54}Mn (Z=25,N=29) is an odd-odd nucleus with proton and neutron numbers around the magic gap 28. It has 3 proton holes and 1 neutron particle (3h-1p) configuration with respect to the ^{56}Ni magic core. The unpaired proton lies in the $1f_{7/2}$ where as unpaired neutron lies in the $2p_{3/2}$ orbitals, which are situated just below and above the shell closures at Z, N = 28. The study of the odd-odd nuclei can help us to understand the residual interaction between proton and neutron. The low lying states in ^{54}Mn are primarily single particle in nature which was reproduced by shell model calculations using OXBASH code up to the spin of 9^+ [1] . But the higher angular momentum states could not be explained by the same calculations. On the other hand, some of the odd-odd nuclei in this region are known to posses collective deformation at higher spins as in the case of the 1p-1h nucleus ^{56}Co [2]. Therefore, it is interesting to revisit the excited states in ^{54}Mn to understand its higher spin states. The complexity in their structure may come due to the different coupling possibility between the two unpaired nucleons. It is worth mentioning that there are efforts to employ this isotope (^{54}Mn) as a cosmic ray chronometer [3].

Experiment

An experiment was performed at VECC with a 36-MeV α beam from K-130 cyclotron using the INGA array with 7 clovers and 1 LEPS detectors [4]. In the same experiment, γ-rays were also observed which resulted due to the beam hitting the Stainless Steel (SS) frame. The analysis of this data provides important information on the nuclei in A ~ 50 - 60 region.

Stainless steel primary consists of nickel, chromium, and iron, the most abundant isotopes of which are ^{58}Ni, ^{52}Cr and ^{56}Fe. Range of 36-MeV α in SS has been estimated to be ~ 0.5 mm which is much smaller than the thickness of the frame (target in this case). So, nuclear reactions of all energies of α-beam from 36 MeV down to the Coulomb barrier took place. Several nuclei in the mass region A ~ 50-60 were produced, and are observed in our data. Our nucleus of interest, ^{54}Mn, has been populated by the reaction ^{52}Cr(^{4}He, pn)^{54}Mn. The PIXIE-16 based digitizer data acquisition system and the IUCPIX package developed by UGC-DAE CSR, Kolkata [5] were used to record and process the data for further analysis using the RADWARE software.

Analysis and Results

A γ–γ coincidence matrix has been formed with add-back energies from the Clover detectors which was analyzed to obtain the coincidence relations between different γ-rays to verify and establish the level scheme of the nuclei. Our first aim was to find out all the nuclei produced in A ~ 50 - 60 region. 9 nuclei from ^{51}Cr to ^{61}Cu were identified from their known level schemes. The ^{54}Mn nucleus was produced with large cross-section and maximizes at E_{beam} = 31 MeV.

A spectrum gated by low-lying 212-keV γ-ray shows most of the known γ-rays in ^{54}Mn (Fig. 1) with an indication of a 146-keV new γ-ray, which is clearly seen in the spectrum gated by 769 KeV γ-ray (Fig. 2).

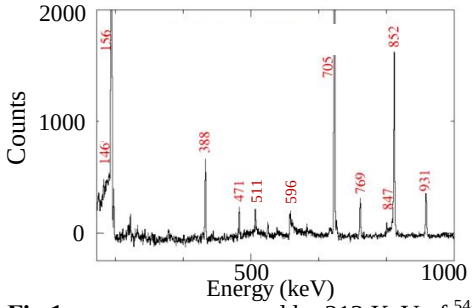

Fig.1 γ-ray spectrum gated by 212 KeV of ^{54}Mn.

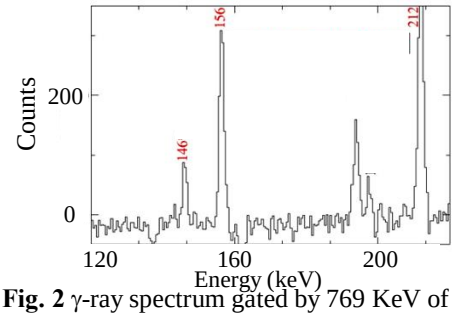

Fig. 2 γ-ray spectrum gated by 769 KeV of ^{54}Mn

A band-like structure with 5 γ-rays, based on a 3rd 7^{+} state at 1669 keV, was reported in [1] which decays to the 1063-keV 6^{+} state by a 596-keV transition. These γ-rays were parallel to the previously known 852-keV 7^{-} → 6^{+} transition. A 852-keV gated spectrum shows 596- and 847-keV γ-rays though they are parallel to 852-keV. The 596-keV is a (n, nôγ) of Ge. This γ-ray is present in other gated spectra also. From detailed analysis, we have placed the 847-keV γ-ray to a new position above 2856-keV 8^{+} state. Also, we did not observe the other γ-rays in the aforesaid band-like structure. So, the 3rd 7^{+} state along with the other states above it are probably not present in ^{54}Mn. The spins of these un-observed states were 7^{+} to 15^{+} [1]. Fig. 4 shows the partial cross-section as a function of spin J, as calculated by PACE-4 code at E_{beam} = 31 MeV. It shows good cross-section with spin up to 15 ħ, indicating that the above states could be observed in our data had these been there in ^{54}Mn.

The DCO ratio (R_{DCO}) and Polarization asymmetry ratio (Δ_{IPDCO}) of the γ-rays were also measured in this work to assign the spin and parity of the states. Spectra of parallel and perpendicular scattered γ-rays projected from the Δ_{IPDCO} matrices, for 2 γ-rays (705 and 1416 keV) with known multipolarities, are shown in Fig. 5.

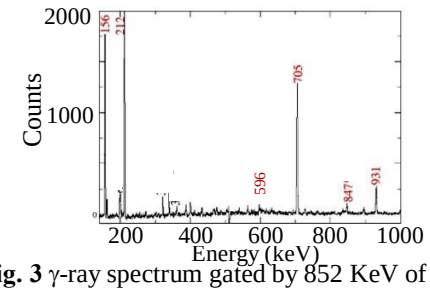

Fig. 3 γ-ray spectrum gated by 852 KeV of ^{54}Mn.

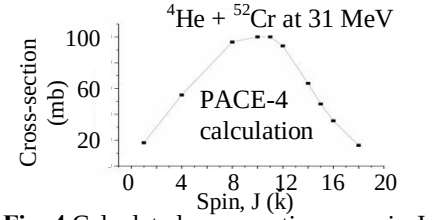

Fig. 4 Calculated cross section vs. spin J plot.

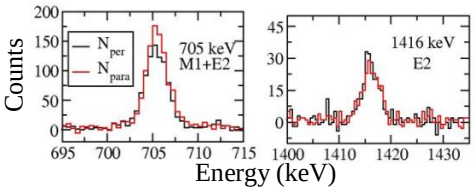

Fig. 5 Parallel (N_{para}) and perpendicular (N_{per}) scattered spectra for two γ-rays in ^{54}Mn.

Conclusion

The analysis of the INGA data obtained from 36 MeV α-beam hitting a SS frame reveals new results on the excited states in ^{54}Mn. Further analysis is in progress to establish a new level scheme of this nucleus and will be presented.

Acknowledgement

We thank the cyclotron operators at VECC for good α beam. We acknowledge the support of INGA collaboration for setting up of INGA at VECC. INGA is partially funded by DST, Govt. of India (No. IR/S2/PF-03/2003-II).

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