INTRODUCTION

The basic problem in nuclear physics is to understand the nature of Nuclear Forces, so as to explain the nuclear properties of excited states such as spin, magnetic moment, nuclear isomerism etc. In order to solve the above problem, we have to excite the nucleus with an external probe. Nuclear physics as it is known today may legitimately be considered to have begun with the discovery of neutron as an easy probe for exploring the structure of the nuclei. Cockcroft used the charged particles as a probe in 1932 for the disintegration of lithium and since then the progress in accelerator technology and hence nuclear spectroscopy became very fast.

A nuclear state is a dynamic configuration of many nucleons and can be described in terms of parameters, viz., excitation energy ($E^*$), total angular momentum or Spin ($J$), Parity ($\pi$), isotopic spin ($T$), electric and magnetic multipole moments ($E\ell$ or $M\ell$), level width ($\Gamma$), lifetime ($\tau$) or reduced transition probability $B(E2)$, multipole mixing ratios ($\delta$), and branching ratios etc. The excitation energy, angular momentum, parity, etc., associated with the nuclear state describe its static or gross properties while the transition probabilities are closely related to the dynamic properties of the nuclear states which provide
information about the relative motion of individual nucleon or group of nucleons. The electric and magnetic moments associated with the nuclear state are determined by the spatial distribution of the protons and neutrons in the given state of the nucleus. These moments are therefore related to the shape and shape variation of the nuclear configuration.

Different nuclear models such as liquid drop model [1], cluster model [2], shell model [3,4], Collective model [5] and Nilsson model [6] were proposed by different workers to explain the behavior of the nucleus. Each of these is applicable in a limited region of the periodic table, but the shell model and the collective model have the credit of being the most successful in explaining the properties of a number of nuclei. The shell model is exceptionally good for nuclei having protons or neutrons near magic numbers. But, it fails to explain the experimental results in the mass region $190 > A > 150$ and $A > 222$, where the predictions of collective model [5] are more meaningful. The Nilsson Model, which is essentially a deformed shell model has been successful in reproducing the single particle properties of the deformed nuclei.

The shell model assumes that each nucleon moves in a common potential produced by rest of the nucleons in the nucleus. The diagonalization of the nuclear Hamiltonian in an infinite dimensional Hilbert space is the general approach to the shell theory calculations. However, for simplicity, in practice, only a few of the single particle
orbits are considered active and available for being occupied by valence nucleons, outside the inert closed shell core. The resulting eigenvalues represent the energies of various states of the nucleus, and the eigenvectors are the corresponding wave functions of the nuclear states. These wave functions together with suitable operators give the multipole moments of nuclear states and the electromagnetic transition probabilities between various nuclear states. The choice of a suitable model space and the effective Hamiltonian is very important for the reproduction of experimental results.

In order to reduce the size of the shell model matrix, it is often desirable to divide the shell model space into a proton space and a neutron space, which are treated equivalent to each other. The Hamiltonian $H$ is taken as $H = H_{pp} + H_{nn} + H_{pn}$, where $H_{pp}$ is the Hamiltonian due to proton-proton interaction, $H_{nn}$ is the Hamiltonian due to neutron-neutron interaction and $H_{pn}$ is the Hamiltonian due to proton-neutron interaction.

The shell theory calculations are unable to account for the existence of non-normal parity states, occurring in some of the nuclei. This can be explained by taking into account the particle hole excitation [7] of the core, in which odd number of particles from the closed shell are promoted to the active orbits (1p-1h, 3p-3h excitations), since the adjacent major shells have the single particle orbits of opposite parities (i.e. non-normal parity). It is often advisable even in the case of normal
parity states to take into account 2p-2h, 4p-4h, ....... excitation to explain the existence of a large number of states having the same angular momentum.

In the nuclei which are far away from the closed shell structure, the neutrons and protons occupying large angular momentum states exert a centrifugal force, which results in permanent deformation or distortion of the nucleus. These deformations are surface effects and a major part of nucleus i.e. the core remains unaffected. In the collective model, it is assumed that a nucleon near the surface of the nucleus moves in an orbit and as it moves, it draws with it a bulge in the ensemble of the other nucleons. This has been compared with the tides in the ocean resulting from the gravitational attraction of the moon as it moves round the sun. The total energy in deformed nucleus is given by

$$E = E_n + E_{rot} + E_{vib},$$

where $E_n$ is nucleonic energy of the states arising due to the motion of loosely bound nucleons. $E_{rot}$ and $E_{vib}$ are the rotational and vibrational energies arising due to the motion of nuclear core with respect to the surface nucleons.

The vibrations in the nucleus are quantized energy units equal to $\hbar \nu$, which are known as phonons. Here $\lambda = 2, 3 \ldots$ correspond to the fundamental vibration shapes. A vibrational state contains an integral number of phonons of each $\lambda$. Each phonon vibration carries an angular momentum $\lambda$ and parity $(-1)^\lambda$. Therefore the vibrational states of energy $\hbar \nu_2$, $\hbar \nu_3$ and $\hbar \nu_4$ have the angular momentum $J^\pi$ equal to
The two phonon vibration of energy $2\hbar v_2$ can have the angular momentum of $0^-$, $2^-$ or $4^-$. The nuclei with large deformation and hence having the large value of quadrupole moments are very well described by the rotational bands. The energy levels in such cases are given by the expression $E_j = \hbar^2 J(J+1)/(2I)$ where $J^n = 0^-, 2^-, 4^- \ldots$ for even-even nuclei and $J = J_o, J_o + 1, J_o + 2 \ldots$ for odd mass nuclei. $I$ is the moment of inertia. Nilsson considered the Single particle motion in a deformed potential. The deformed core is taken as the ground state with oblate or prolate deformation and strong coupling between the particle and the deformed core is considered.

Nuclear spectroscopy deals with the determination of the various parameters of nuclear configurations. In order to study these parameters, the nuclear levels must be excited either through decay of radioactive nucleus or through nuclear reactions. In the radioactive decay, the parent nucleus is in a metastable state and decays to various excited states of the daughter nucleus through $\alpha$, $\beta$ or $\gamma$ emission. The radioactive method, though convenient, is however subject to the availability of the radioactive nuclei. It has limitations that the study of very short lived isotopes is difficult and long lived isotopes are not very easily produced. Moreover only a few low-lying levels are populated in most of such cases.
The nuclear levels are therefore, excited through nuclear reactions using charged particles as projectiles from accelerators and the in-beam study of deexcitation products of various excited levels is performed to extract information about nuclear levels.

The detailed theories of nuclear reactions were patterned after the liquid drop and compound nucleus model. In the compound nucleus theory, it was assumed that a nuclear projectile incident on a nucleus would interact strongly with all the nucleons in the nucleus and quickly share its energy with them. In the optical model theory of nuclear reaction it was proposed that an incident nucleon would interact with the nucleus via the shell model potential. The success of the optical model suggests that the Bohr theory of compound nucleus needs some modification. A more general scheme of nuclear reaction has been described by Weisskopf. According to him the nuclear reaction proceeds through three stages: the independent particle stage, compound nucleus stage and the final decay stage. During the first stage, the interaction between the incident wave and the nuclear potential may lead to partial reflection of the incident wave, called shape elastic scattering. The part of the wave function which enters the nucleus undergoes absorption. This process leads to the second stage. Some of the possible absorption processes are: I. Ejection of nucleons in collisions with incident particle as direct interaction. II. Multiple collisions of the incoming particle with several nucleons of the target nucleus. III. The excitation due to some type of collective motion such as surface vibration of the

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target nucleus. IV. The formation of compound nucleus without remembering details of its initial stage of formation. The third stage of the reaction is more or less rapid transition to the final state. It is concerned with the way the reaction products are produced, i.e. on the second stage, either disintegration or deexcitation of the compound nucleus will occur. Actually there is no sharp division between the different possibilities in a compound system. The optical model potential utilized in the present investigations was the customary Woods-Saxon type with surface absorption plus a real spin orbit term of the Thomas form as $V(r) = V_{re}(r) + iV_{im}(r) + V_{so}(r)$. The optical model potential used to describe the interaction of a nucleon with a nucleus is complex. The imaginary part $V_{im}(r)$ accounts for the absorption and the real part $V_{re}(r)$ for reflection of the incident nucleons. $V_{so}(r)$ is the spin-orbit interaction term. This model has been useful in interpreting nuclear scattering from low energies up to relatively high energies. The transmission coefficients are calculated in generalized form $T_{ij}(E)$, from the real and imaginary parts of the elastic scattering amplitudes $C_{ij}(E)$ as

$$T_{ij}(E) = 4(1mC_{ij} - |C_{ij}|^2).$$

In the Hauser-Feshbach theory, it is assumed that the compound nucleus states overlap so strongly as to form a quasi-continuum and their relative phases are distributed randomly. A further inherent assumption is that the partial widths of the respective compound nucleus levels are essentially constant. Relinquishing this latter assumption, Moldauer [8] has replaced it with the supposition that the
When the energy of the projectile is relatively large to pass the Coulomb barrier, it may reach the surface of the nucleus and interact with nuclear forces through optical model potential and the projectile dissipates whole of its kinetic energy within the target nucleus. The resulting configuration is known as "compound nucleus". At high energies, the reaction proceeds through one-step process, i.e., direct mode of interaction. These different modes of reaction mechanism involve appreciably different times of interactions. The characteristic interaction time for compound nucleus mode is about $10^{-19}$ second [10], while for the direct process, it is of the order of transit time ($\sim 10^{-23}$ sec.) of the incident particle over the nuclear diameter.

The lifetimes of the excited states were measured using Doppler Shift Attenuation (DSA) technique. For the determination of spins and parities of nuclear levels and the mixing ratios of $\gamma$-transitions, the angular distribution data was analyzed using the statistical model [11] of compound nucleus. The proton energies used in the experiments were 2-5 MeV. As such low energies of incident projectile, the contribution due to direct interactions can safely be assumed to be negligible [12]. The low-lying levels of $^{93}$Nb have been studied through Coulomb excitation. In other cases the contribution due to Coulomb excitation and (p,\$\gamma$) process were found relatively negligible. Since the compound nucleus theory reproduced the well known spin of the lower levels in the nuclei under investigation, the use of this theory for the analysis of the present experimental data is justified.
The purpose of the present work has been to study the f-p shell nuclei to extract their nuclear properties. The Q-value of (p,n) reactions for odd mass nuclei is generally low and the reaction cross section is reasonably large. Due to this reason the odd mass nuclei have been chosen for the study. The energy levels, the spins, parities, and lifetimes were measured for $^{93}$Mo, $^{73}$As, $^{71}$Ge, $^{55}$Mn and $^{93}$Nb nuclei. The experimental results are compared with the theoretical prediction based on various nuclear models.
REFERENCES

   D. M. Dennison, Phys. Rev. 57 (1940) 454.
   Phys. Letters 8 (1964) 70.
   Rev. Mod. Phys. 36 (1964) 1079.
