CHAPTER I

INTRODUCTION

In shell-model the most general and complete description of an n nucleon system requires the knowledge of the complete set of coefficients for coupling the last nucleon to all possible physical states of the (n-1) nucleon system. A numerical solution of the problem, in all its generality, involves the diagonalization of the residual interaction matrix in infinite dimensional Hilbert space, which is a prohibitive problem. As the admixture coefficients for shell-model configurations widely separated in energy are expected to be small, in practice, one works in a limited configuration space the choice of which depends upon the nature of a particular problem and the data, one is trying to interpret.

In the present work, we have tried to explain-within the framework of shell model-the observed multiplicity, spectroscopic strength distributions and electromagnetic decay properties of residual nucleus states, excited via single proton transfer to target nuclei in (f-p) shell and ($1g_{9/2}$-$2d_{5/2}$) shell regions of the periodic table, by taking core polarization effects into account. Single-nucleon transfer reaction data have considerably enhanced our knowledge of nucleon parentage as one directly measures the component, in a particular physical state, of a nuclear state (the single-particle state) obtained by adding a nucleon in a definite spherical orbit to a definite target state. In the weak coupling limit[1], the single-proton transfer strength for addition of a proton to a valence orbit (empty or partially filled for neutrons), lying above orbits occupied by neutrons and having vacancies for protons, of a target nucleus, is split up into components having isospin values $T_0+1/2$ and $T_0-1/2$. Experimentally, the $T_<$ strength is seen to be severely fragmented and distributed in a region a few MeV around the centroid of $T_<$ group of states. This fragmentation arises due to the mixing of the weak coupling $T_<$ state with the background states having the particle coupled to the various excited states of the core. The present work aims at investigating, beyond what has been reported earlier, the detailed structure of residual nucleus states in the isospin-$T_<$ band. This involves a knowledge of the nature of core-polarization states lying in the vicinity of weak coupled $T_<$ state that are likely to be mixed strongly with it. We have also calculated the structure of $T_>$ states, but the mixing of $T_>$ states with the background $T_<$ states has not been considered.

The weak coupling state having $T_>=T_0+1/2$ can also be generated from its neighbouring (target+n) parent state by the isospin lowering (T_- operater) and is referred to as the Isobaric Analog State (IAS) of the former. It is found to have a large component of configuration states in which the added proton is interchanged with a neutron from one of the lower orbits. With the assumption that the isobaric analog states mix weakly with the background $T_<$ states, a one to one correspondence can be established between the $T_>$ states excited via proton stripping and the states excited via neutron stripping to the same target. The $T_>$ states excited via single-proton transfer, therefore, contain the same information about the neucleon parentage as that obtained via single-neutron transfer reactions. The weak coupled $T_<$ state has a structure similar to that of the analog state and is referred to as the Antianalog State. All information about the proton parentage is contained in the strengths measured for the $T_<$ levels excited via single-proton transfer reactions.

The first detailed calculation to explain the observed spreading of $T_<$ single-particle strength over a number of states, considered to be due to the mixing of the weak coupled $T_<$ state (Antianalog State) with the isospin de-excited core-polarization states, was done by Bansal[2)] for the simple case of proton transfer to closed neutron shell targets ^{48}Ca and ^{36}S. In this model of Core Polarization, referred to as the Isospin Excitation Mode, the isospin of the core is lowered by unity as compared to that of the target ground state. This particular mode of core polarization, described in detail in Chapter V(Section I), forms the basis of our subsequent extensions of the Core Polarization Model.

In the earlier[3-6] shell model calculations, attempts have been made to explain the observed multiplicity of $3/2^-$ levels in ^{51}V, ^{53}Mn and ^{55}Co by mixing the $3/2^-$ single-particle state with additional $3/2^-$ states arising due to the proton occupying $1f_{7/2}$ orbit and orbits lying higher than $2p_{3/2}$ orbit, whereas the eight neutrons in $1f_{7/2}$ orbit remain undisturbed. In this approach sufficient number of states do not, theoretically, become available in the desired energy region to account for the observed multiplicity of $3/2^-$ levels in the nuclei being considered.

In such cases and in other situations, the isospin excitations of the core incorporated in the Core-Polarization Model calculations play an important role in the description of spreading of strength in the spectra of residual nuclei, obtained via proton addition to suitable targets.

The case for the inclusion of isospin excited core-polarization states for the description of $3/2^-$ states in the (f-p) shell nuclei is strengthened when one looks at the experimental transition strengths for M1 decay of the analog state to the strongest observed $T_<$ state. Recent studies of a number of (f-p) shell nuclei, ^{49}Sc[7], ^{51}V[8] and ^{57}Co[9], in particular, have shown that the transition rates for M1 transitions from the Isobaric Analog State (IAS) to the strongest $T_<$ state (having the same spin and parity as the IAS) are strongly inhibited as compared to the single-particle transition rates. Maripuu[10] and Hirata[11] have shown the hindrance of M1 transition strengths, for IAS to the strongest $T_<$ state transition in ^{49}Sc and ^{51}V, to be due to the $T_<$ state having an appreciable component of isospin de-excited core polarization state with core angular momentum equal to unity. The hindrance effects in $T_>$(IAS) state to the strongest $T_<$ state M1 transition are also closely related to the inhibition of the observed Gamow-Teller β-decay to the $3/2^-$ level at 3.08 MeV in ^{49}Sc, explained earlier by Bertsch and Damgaard[12] using the same model scheme as that used by Bansal[2]. Maripuu[10] has calculated the energy eigen-values, eigenfunctions and M1 transition rates for $3/2^-$ levels in ^{49}Sc nucleus but has calculated, in the case of ^{51}V nucleus, only the amplitude of a single core polarization state (having core angular momentum equal to unity), responsible for producing the observed cancellation effects in M1 transition strength for $3/2^-T_>$ state (IAS) decay to the strongest $3/2^-$ $T_<$ state.

In most of the reported shell model calculations[3-6] for (f-p) shell nuclei having $N \geq 28$ and $20 < Z < 28$, assuming an inert ^{48}Ca core, the basis states in which the protons occupy $2p_{3/2}$ and higher orbits suffer from the flaw of not having definite isospin. In the reported cases[13], where good T states have been constructed, the isospin excitations of the core have not been included in the model space. In the case of ^{55}Co nucleus, however, R.Shoup et al.[15] have calculated the properties of $3/2^-$ levels taking isospin excitations of the core into account and using KB interaction[16] with its part characterised by J=1 and T=0 being made more attractive by 1 MeV.

We have concentrated on the $3/2^-$ levels in nuclei ^{51}V, ^{53}Mn and ^{57}Co ,which have not earlier been successfully described, and investigated the importance of isospin excitations of the core for explaining the observed multiplicity, relative energy spacings, spectroscopic strength distributions, M1 transition rates for analog state decay to $T_<$ level,and E2 transitions to ground state. Also included in the model space are the basis states in which the active core nucleons are coupled to allowed values of angular momentum, other than the target ground state angular momentum, as these are expected to affect the spectroscopic strength distribution. For the $3/2^-$ levels in ^{49}Sc and ^{55}Co we have repeated the calculations done earlier[2,10,14,15] using a modified version of Kuo and Brown Interaction.

In the nickel region, with ^{56}Ni as a closed core, there is expected to be a structural similarity between the $5/2^-$ states in ^{61}Cu excited via $1f_{5/2}$ proton addition to ^{60}Ni (ground state) and the $3/2^-$ states in ^{49}Sc nucleus. Thus isospin excitations of the core are important for a description of $5/2^-$ levels in copper isotopes. We have studied these in ^{61}Cu and ^{63}Cu nuclei.

Another interesting region for core-polarization studies is the region with $N \geq 50$ and $40 < Z < 50$. We have done[17] detailed calculations for $5/2^+$ states in ^{91}Nb and ^{93}Nb nuclei excited via $2d_{5/2}$ proton addition to ^{90}Zr(g.s.) and ^{92}Zr(g.s.) respectively. Though a number of shell model calculations [18-20] have been done earlier for low-lying levels in ^{91}Nb, none have been reported for levels in the region above 3MeV excitation, where most of the $2d_{5/2}$ proton transfer strength has been experimentally observed.

In the case of ^{49}Sc and ^{61}Cu, the isospin excitation mode of core-polarization alone does not reproduce the observed multiplicity of $3/2^-$ states. In the model space for these nuclei we have, therefore, included a selected set of basis states having the added nucleon coupled to Two-Particle and Two-Hole (2p-2h) excited core states. The characteristics of the residual nucleus configuration states having a (2p-2h) excited core are discussed in Chapter V (Section I).

The choice of effective two-body interaction is closely linked with the choice of configuration space. Sum Rule Methods[21] have been usefully exploited to extract relevant average two-body interaction energies from the experimentally observed centroids of $T_>$ and $T_<$ states, excited via single-proton transfer to nuclei in (f-p) shell as well as in $(1g_{9/2}-2d_{5/2})$ shell region. These averages serve as constraints on the effective two-body interactions used in the detailed calculations. For detailed calculations in (f-p) shell nuclei, we have used parameter free realistic two-body interactions derived from free nucleon-nucleon potentials. In particular, in the $(1f_{7/2}-2p_{3/2})$ region, Kuo and Brown (KB) Interaction[21] as well as Modified Kuo Brown Interaction have been employed, the latter is an effective interaction recalculated from the original KB Interaction for use in a smaller model space. Yale and Reid Interactions derived[22] from free nucleon-nucleon Yale and Reid potentials respectively, have been used for detailed calculations in ^{61}Cu and ^{63}Cu nuclei. No calculations, using Modified Yale Interaction and Modified Reid Interaction, have been attempted because of the poor agreement shown by the average two-body energies extracted from these interactions with those obtained via Sum Rule Methods.

In the $(1g_{9/2}-2d_{5/2})$ region, we have used a Phenomenological Interaction derived from experimentally observed two-body spectra in the region.

The various aspects of the effective two-body interactions employed in different regions are discussed in detail.

in Chapter IV.

We have done the calculations in neutron-proton formalism. A brief account of the Second Quantization Techniques, as employed in shell model calculations, is given in Chapter II. Most of the time the notation followed is the same as used by J.B.French[23]. The construction of multishell basis states in neutron-proton representation is discussed, and the matrix element of a given operator between given (n-p) basis states expressed in terms of single orbit identical nucleon reduced matrix elements.

In Chapter III (Section I), the second quantized version of the isospin operater in neutron-proton representation is derived and the construction of multishell states having definite isospin value and good symplectic symmetry discussed. Section II of Chapter III deals with the (n-p) representation of the Hamiltonian operator, single nucleon transfer operator and the electromagnetic transition operators. Also outlined in Section II is the procedure used for calculating the matrix elements of an operator in the final good JT basis.

The detailed calculations involve the usual diagonalization of the Hamiltonian operator in the chosen basis to obtain the energy eigenvalues and eigenfunctions which are further employed for the calculation of the spectroscopic factors, reduced M1 transition strengths and reduced E2 transition strengths.

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