CHAPTER I

Introduction.

The nuclei in general display two major qualitative features interpretable in terms of the onset of deformations and the occurrence of pairing. These features reflect the two dominant characteristics of the effective interactions namely its deformation-producing and pairing tendencies. It was the recognition of the importance of these two tendencies which led to the schematization of the effective interactions.

The quadrupole-quadrupole interaction was thus introduced to represent the essence of the deformation-producing tendency of the effective interaction. The extreme pairing interaction - an interaction operative only in the J=0 two-particle states - was on the other hand considered to take care of the dominant part of the general pairing tendency of the two-body effective interaction.

This schematic interaction had simplicity as well as physical reasonability. It proved immensely useful in the study of the various aspects of the nuclear structure that result from an interplay of the deformation and pairing tendencies of the effective interaction.

The actual effective interactions, obtained either
phenomenologically or from the free N-N interaction, are however quite complex; they can not be written in terms of just a sum of the J=0 pairing and quadrupole-quadrupole components. It is not possible to assess the deformation-producing and the pairing tendencies of an effective two-body interaction such as the Kuo-Brown interaction\(^1\) by staring at the large number of matrix elements that specify it.

An analysis of the effective interactions in terms of its deformation-producing and pairing tendencies would however appear worthwhile in view of the important role that these two dominant qualitative aspects play.

In the first part of this thesis (Chapters II and III) we have tried to elucidate the deformation-producing and the pairing aspects of the effective interactions in the framework of the Hartree-Fock (HF) theory.

The HF theory which is conventionally used to obtain a description of the low-lying states of the nuclei can also serve to define unambiguously the criterion for examining and comparing the deformation-producing and the pairing tendencies of the effective interactions.

The various multipole moments of the HF state generated by the two-body interaction reflect the overall
field-producing tendency of that interaction. An interaction consisting predominantly of a quadrupole-quadrupole component would be expected to lead to a HF state having a large value of the quadrupole moment. The deformation-producing aspect of an interaction is thus best brought out by examining the various multipole moments of the HF state that the interaction gives rise to.

The general pairing aspect of the interaction, on the other hand, manifests itself in giving rise to the instability of the HF state by exciting a pair of particles from it. A criterion for judging the general pairing aspect of an interaction is thus provided by the extent to which the HF state produced by the interaction is susceptible towards two-particle two-hole (2p-2h) excitations from it. A quantitative measure of the general pairing tendency of an interaction would thus be the total intensity of the 2p-2h configurations that the interaction can admix to its own HF state.

It is with the above considerations in mind that we have examined, in chapter II, first the deformation-producing aspects of the full interaction, its T=0 as well as its T=1 component. Later in chapter III we have carried out a comparison of the general pairing tendencies of the two T-components of the interaction.

It appears that an over-emphasis on the pairing
aspect of the $T=1$ interaction has resulted in an underestimation of its deformation-producing tendency. We shall show in chapter II that the $T=1$ interaction has almost the same deformation-producing tendency as the $T=0$ interaction.

In chapter III we shall explicitly show that the $T=1$ interaction is only slightly more pairing in character than the $T=0$ interaction.

In the second part of this thesis (chapter IV) we illustrate how one can use the available experimental information in the framework of the FF theory to examine and correct certain deficiencies of the effective interaction. The simple criterion that the deformations extracted from the effective interactions should be at least qualitatively consistent with the ones obtained empirically from the available BE2 (0→2) systematics in the 2$p$-1$f$ shell enables one to modify the effective interaction in the shell.

The question of the extent of the 1$f_{7/2}$ sub-shell closure for Ni$^{56}$ ground state has also been examined quantitatively in chapter IV. It is estimated that the ground state of Ni$^{56}$ as given by the Kuo-Brown effective interaction modified to satisfy the restrictions imposed by the BE2 (0→2) systematics contains about 13 particles in the 1$f_{7/2}$ sub-shell.
In the third part (Chapter V) we have studied the microscopic structure of some even-even isotopes of Germanium and Selenium in the framework of the Hartree-Fock-Bogoliubov (HFB) method. We have employed an effective interaction\(^2\) obtained for the valence space of the \(2p_{3/2}, 1f_{5/2}, 2p_{1/2}\), and \(1g_{9/2}\) orbits by Kuo. The interaction is renormalized for the core-excitation effects due to the \(\text{Ni}^{56}\) core.

The HFB calculations for Germanium and Selenium isotopes reveal certain very interesting features. We find large quadrupole deformations for nuclei around neutron number \(38\). The \(1g_{9/2}\) orbit is seen to acquire an occupation probability greater than zero for these nuclei because of pairing effects and the \(2p-1f\) shell gets emptied. This results in large deformations. A good qualitative agreement with the available experimental results is obtained for the deformations of various nuclei in the upper p-f shell. The neutron and proton pick-up strengths are also calculated.

In the fourth part of this thesis (Chapter VI) we have considered a schematic model for the description of the low-lying collective states of nuclei.

The \(J\) states projected from the HF or HFB intrinsic states are usually found to provide a good description of the low-lying states of the nucleus.
The structure of these J-projected wavefunctions is in general seen to be very complicated. However the states $|J_p \rangle$ and $|J_n \rangle$ projected respectively from the proton and neutron parts of a HF intrinsic state separately tend to exhibit a "quasi-rotational" behaviour in a well-deformed nucleus. The low-lying states $|J \rangle$ for the nucleus can therefore be described in terms of the various couplings of the collective states $|J_p \rangle$ and $|J_n \rangle$.

In chapter VI we discuss the coupling of two rotationally collective set of states by various multipole-multipole interactions. We also discuss some interesting implications of assuming rotational collectivity for a finite set of angular momentum states.
REFERENCES


2. T.T.S. Kuo, private communication to K.H. Bhatt
PART ONE

THE USE OF THE HARTREE-FOCK THEORY AS A TOOL FOR EXAMINING THE PROPERTIES OF THE EFFECTIVE INTERACTION

1. Non-pairing Aspects of the T=1 Interaction

2. Instability of the Hartree-Fock State as a Measure of the Pairing Tendency of an Interaction