Chapter (I)

Introduction

The study of the angular distribution of γ-radiation from orinted nuclei has yielded considerable insight into the properties of nuclear levels and their radiations. In particular the static nuclear electromagnetic moments and the multipole characters of the radiation fields may be accurately determined. This information is essential for understanding the structure of the low-lying levels, nuclear size, the shapes of nuclei, and the distribution of nucleons in the nucleus.

Many measurments, associated with γ-ray and internal conversion have been done[1-4]. When γ-ray and conversion electron emission occur in the decay of an excited nuclear state, more than one multipole radiation is often allowed by the selection rules on the nuclear spin and parities. While any multipole order between the sum and the difference of the initial and final spins is allowed, the strong dependence of the transition probabilities on the angular momentum carried off restricts the observable orders to the lowest ones[5]. For example with a very few recently discovered exceptions, in transitions where multipole orders $\lambda \geqslant 1$ are allowed and parity changes, E1-radiation totally dominates with M2 $\leqslant 1\%$ [6]. However, when the selection rules allow, E2-radiation often dominates the M1 component[6].

It is remarkable, here, to state that the experimental measurments, for the γ-ray and conversion electron emission, are a multipole Coulomb excitation measurments, for which a very heavy projectiles are usually used[7]. This method is favourable to investigate the high spin state of the deformed nuclei in both rare - earth and actinide regions[2,7-10]. In other words the Coulomb - excitation offer the advantage of giving information not only on the energies of the excited states but also on electromagnetic properties. Additionally this method has become feasible a few years ago with the advent of heavy-ion accelerators such as UNILAC at GSI (West Germany).

The purpose of the present work is to study the energy levels and the electromagnetic properties of some rare earth and actinide nuclei in the framework of the rotation - vibration model beside the old[11] and new[12] versions of Greiner's model. The electromagnetic properties are namely the E2 - transition and M1-transition probabilities (B(E2), B(M1), the E2/M1 mixing ratios (δ(E2/M1)) and the gyromagnetic factors (g_R- factors). In our study we shall consider both : the interband transitions, which occurs between two members found in two different bands, and the intraband - transitions, which occurs between two members found in the same band. The B(E2)-values, the B(E2)-branching ratio, the magnitude and the sign of δ(E2/M1) and g_R-factors are well suited to investigate the influence of the rotation - vibration interaction and provide a sensitive tests on nuclear models. In fact δ(E2/M1) may be a more sensetive parameter in many instances than the reduced transition probability, for example a B(E2) or B(M1) value. This is because a δ-value contains matrix element values, so that the relative phases of the electric and magnetic multipole operators are preserved, whereas a transition probability depends on the square of a matrix element.

Our study have been done as following. At first we have determined the values of the prior parameters of the rotation - vibration model (E_{rot} , E_β , E_γ) by fitting the energy levels of the three lowest bands. E_{rot} , E_β and E_γ represents the lowest energies of the ground - state (rotation), beta -, and gamma - band, respectively. Secondly the value of the forth parameter, nuclear deformation parameter, have been determined by fitting the E2-transition probability of the intraband transition $2^+_g \longrightarrow 0^+_g$. For the second step the homogenous charge distribution hypothesis of the rotation vibration theory had been considered. Thirdly and in the light of the first manipulation[11] of Greiner's model we have derived the general equation of the M1-reduced matrix elements. Fourthly the E2- reduced matrix elements have been calculated, again, in the framework of the second manipulation[12] of Greiner's model. This second manipulation is associated with a new parameter known as the proton-neutron deformation difference. As an indication about Greiner's model, the basic idea is that, because of the different pairing forces for the nucleons[13,14], protons and neutrons have some what different deformations[15]. In addition, the proton deformation had been expected to be smaller than the neutron deformation ($\beta_o(p) < \beta_o(n)$), since the pairing force of proton greater than the pairing force of neutron. In the framework of the 1st and 2nd manipulation of Greiner's model both of the mixing ratios and g_R-factor have been calculated for some rare earth and actinide nculei. It is important to state, here, that the Greiner's model is associated with the nonhomogenous distribution for the nuclear charge.

A larg number of models and submodels have developed and applied to the study of the energy levels and the magnetic properties. Among these models and submodels we shall give below a shorthand notations for some of them. Where a most of our theoretical results of energy levels, B(E2)- values, B(E2)- branching ratios and δ-mixing ratios will be compared with the corresponding theoretical results of these models.

1) The asymmetric rigid rotor model:-

Davydov and Filippov[16] have extended the rotational model of Bohr and Mettelson[17,18]. They applied this extension to derive an expressions for the reduced E2-transition probabilities between a members of the g.s.-band and γ-vibrational band taking into account that the 2_γ^+ - state results from the rotation of a rigid trixial nucleus about the principle axis with a smallest moment of inertia. In other words, they described, the low - lying states of an even - even nuclei, in terms of rotations without change in the shape. Davydov and Rostovsky[19] revised the previous model by considering the shape of the nucleus changing as it pass into an excited state. The change of the nuclear shape in excitation situation leads to a connection of rotational motion with beta and gamma vibrations. Gupta et al.[20]

had found that there is a remarkable supremacy for Davydov and Filipov over Davydov and Rostovesky estimations. This leaded them to suggestion that the inclusion of the interaction of the rotation with the beta - vibration, by Rostovsky, appears to be responsible for disparity of B(E2)-values from experimental rates[20]. Also, they had concluded that the theory of transitions between two levels of spin 2 without adiabatic approximation, which was developed by Rostovsky, mainly for E0- transitions, are strongly forbidden in the adiabatic approximation theory of Filippov.

2) The projection model:-

This model is proposed by Lipas at al[21]. It is a geometrical model with only two parameters in its basic (isotropic) form and four parameters in its more complete (anisotropic) form. The parameters of the isotropic projection model are fixed by fitting the two lowest ground - state - band energies, states 2_g^+ and 4_g^+. The parameters of the anisotropic projection model are fixed by fitting the energies of of the 2_g^+, 4_g^+, 0_β^+ and 2_γ^+ states.

This model, isotropic and anisotropic versions, have been used for the computation of (quasi) ground - state, beta and gamma - band excitation energies. Also, with one additional parameter it gives E2 and E0 transition strengths. At the same time it has been found that the anisotropic version gives agreement with the predicting experimental data of the energy levels, B(E2)- values and B(E2)- branching ratios better than those which associated with the isotropic version.

As a general conclusion , Lipas et al.[21] had observed that the projection model with two or four parameters are not capable of an accurate description of the detailed spectra and transitions. Therefore they suggested that a modification can be obtained, for the theoretical results, if one use an extended projection model with more parameters[22].

3) The interacting boson model:-

This model[23-31] has gained a great attention and a considerable popularity both among experimentalists and theorists. The model is founded on algebric rather than geometrical ideas, with like - nucleon pairs being considered as bosons. There are two versions for this model, one of them is known as IBA-1[22-26] and the other is known as IBA-2[28-31]. The IBA-2 is a more detailed version of IBA-1 where the proton and neutron degrees of freedom are treated explicity and are represented by proton s and d bosons and neutron s and d bosons.

According to its shell model basis, the IBA-2 hamiltonian includes interactions between like bosons (proton - proton bosons and neutron - neutron bosons) which are very different from those between proton and neutron bosons. Additionally IBA-2 can correctly reproduce the 1^+ levels which were recently discovered by electron scattering in deformed nuclei[32-33]. Such levels cannot be described by IBA-1.

A practical difficulty of applying IBA-2 is that it has many more states than IBA-1. For example, in case of ^{178}Hf, the number of IBA-2 states for J = 6 is greater than the corresponding number in IBA-1 by about a factor of 60[34]. The enormous number of IBA-2 states was the main obstacle in the application of IBA-2 to strongly deformed nuclei such as ^{178}Hf or ^{168}Er. Recently Novoselsky[34] developed a new computer program, BOSON2, which can deal with very large matrices in the boson space. With the help of this code he has successfully described the ^{178}Hf-nucleus in the IBA-2 formalism. The agreement with the energy levels of the three lowest bands was good while it was, for the highr bands, as bad as in IBA-1 results, but not worse. In addition, the results, which associated with E2-transitions (branching ratios) from the β-and γ-bands to g.s.-band, were in better agreement with the experimental data, especially for $\beta \rightarrow$g.s. transition than the IBA-1 results.

4) <u>The dynamic deformation model</u>:-

There are two versions for this model[35]. The 1$^{\underline{st}}$ one is known as the dynamic pairing plus quadrupole model (DPPQ) and the dynamic Nilsson, Strutinsky and Belyaev model (DNSB). There are many differences between the DPPQ model and the DNSB model. Some of these differences will be listed below.

In the DPPQ model, the potential energy of deformation of the nuclear shape is calculated via an expression obtained in the time - dependent Hartree - Bogolyubov treatment of the pairing plus quadrupole hamiltonian, this is an approximation to the self consistent Hartree - Fock approach[36]. On the other hand, in the DNSB model the potential energy of deformation, of the nuclear shape is calculated as a sum of two parts: a macroscopic part arising from the deformation of the liquid drop or droplet (representing the contribution of single particle levels far from the Fermi surface), and a microscopic part attributed to the nonuniform energy distribution of single - particle levels[37].

in the DPPQ model there are four parameters : namely the strength of the quadrupole force, whose value is determined by fitting the ratio E_{4^+} / E_{2^+} ; a renormalization factor, whose value is determined by fitting the energy E_{2^+} ; an effective charge parameter, whose value is determined by fitting the $B(E2\ ;\ 0^+ \rightarrow 2^+)$ value ; and a renormalization factor for the three gyromagnetic ratio functions, whose value is determined by fitting the magnetic moment μ_{2^+}[36]. In contrast to the DPPQ requirements, the DNSB model is almost parameter free[35,38].

Kumar et al.[36] had concluded that probably a more extensive study of the DNSB parameters is required before it can be definitely concluded that this model is generally inferior to the DPPQ model.

In our study we shall consider some rare earth nuclei as ^{150}Nd, $^{152-154}Sm$, $^{154-160}Gd$, ^{160}Dy, ^{166}Er, $^{172-174}Yb$, $^{174-180}Hf$ and two members from the family of the actinide nuclei as $^{230-232}Th$. These nuclei are extended from the soft nuclei region to the strong deformed nuclei region. In the same time a recent experimental data and a different theoretical predictions, for these nuclei, are available and applicable which allow us to analyse and discuss our theoretical results adequately. In addition, the motion of the nucleons, inside these nuclei, can take a collective aspect which is a main phenomena in the formulation of the rotation - vibration model.

The ^{150}Nd-isotope[39-41], the ^{152}Sm-isotope[42-44] and the ^{154}Gd-isotope[36,45-47] are located at the abrupt onset of deformation in the rare earth region. In other words they are situated at the beginning of the deformed region which extends from A = 150 to 190. This sudden deformation onset has been related to the disappearance of the effect of a Z=64 proton subshell closure[42]. As a comment on these transitional nuclei : ^{150}Nd, ^{152}Sm - and ^{154}Gd - isotope, we shall try to give a general features of them. These nuclei are generally discribed as a soft rotors. Therefore as the nuclear spin increases the degree of deviation from purely rotational behaviour increases[41]. It has been found that the deviation from rotational model predictions are greater for the β-vibrational than for the γ- vibrational bands[48]. The ground - band energy spacings for these transitional nuclei has been found to be similar, while the β-band is based at 675, 685 and 681 Kev in ^{150}Nd, ^{152}Sm and ^{154}Gd, respectively. In addition the mixing parameter, which associated with contributions from β-vibration, indicates that the extent of mixing of the g.s.-

band with the β-band is nearly identical for these nuclei[41]. Furthermore the B(E2) values, which related with the ground - band states, are extremely similar for these nuclei. Finally, the M1- admixtures in the transitions from the γ- and β- vibrational bands to the g.s.-band are consistently small in the transitional nuclei[49]. This general feature has been confirmed by Kumar et al.[36], who found that the interband transitions, from β- band to g.s.-band and from γ-band, are largely E2.

The ^{154}Sm- isotope[43,44,50], $^{156-160}$Gd-isotopes[51-55], ^{160}Dy- isotope[56-58], ^{166}Er- isotope[59-64] and $^{172-174}$Yb - isotopes[2,3,33,65-67] are more strongly deformed than the transitional nuclei. The deformed nuclei shows a well developed γ- vibrational bands which charactrize the deformed region[51]. In addition these nuclei lies close to the SU(3) limit of the interacting boson model of Arima and Iachello[25]. The B(E2) values, which are associated with a transitions from g.s.-band to β- band, are at least an order of magnitude less than those which associated with a transitions from g.s. band to γ- band. This seems to be a characteristic feature of the even - A deformed nuclei in the rare - earth region. At least this is true for the $^{156-160}$Gd and ^{160}Dy nuclei[57].

The $^{174-180}$Hf- isotopes[34,68-72] provide an interesting family deformed nuclei which are amenable to study by both radio active decay and nuclear reactions. For both the even-even Hf - isotopes and the even - even Gd- isotopes the region of deformation is large since with increasing neutron number N, the Hf- isotopes go from the well - deformed ^{174}Hf- isotope to the more softly deformed ^{180}Hf- isotope, while the Gd - isotopes go from ^{152}Gd- isotope at the onset deformation with N = 88 to the well deformed ^{160}Gd- isotope[72].

A numerous investigations have been performed to study the collective structure of well deformed even - even actinide nuclei ($228 \leqslant A \leqslant 250$). Using multipole Coulomb excitation with very heavy projectiles, ground - band levels up to $I \simeq 30\ \hbar$ have been assigned and corresponding B(E2) - values have been determined[73-81]. It is found that the ground band E2 - matrix elements, in the actinide region, tends to zero as the spin increases, for instance it becomes zero at I_{max} = 24, 26 and 28 $\hbar$ for ^{232}Th, ^{234}U and ^{236}U, respectively[7]. A further point of interest in the actinide nuclei involves the presence of relatively large equilibrium hexadecapole deformations in addition to the usual quadrupole deformation[61,74]. The presence of a small static hexadecapole deformation can have important effect on the equilibrium shapes of deformed nuclei. For example, using a Woods - Saxon potential Gotz et al.[82] have found a presence of small negative hexadecapole deformation in the shape changes the quadrupole deformation from oblate to prolate as in case of tungesten and osmium isotopes[83].

Also as an observation about the even - even deformed nuclei, in both rare earth and actinide nuclei, Warner and Gosten[84] have noticed that these nuclei characterized by a weak ground - beta couplying. Also they observed that these nuclei shows drastic changes in the moments of inertia of their g.s.-band at spin values I-12-16[84].