Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 940 (2015) 279–296

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Chiral symmetry in rotating systems

Sham S. Malik

Department of Physics, Guru Nanak Dev University, Amritsar-143005, India

Received 3 March 2015; received in revised form 28 April 2015; accepted 6 May 2015

Abstract

The triaxial rotating system at critical angular momentum $I \geq I_{band}$ exhibits two enatiomeric (the left- and right-handed) forms. These enatiomers are related to each other through dynamical chiral symmetry. The chiral symmetry in rotating system is defined by an operator $\hat{\chi} = \hat{R}_y(\pi)\hat{T}$, which involves the product of two distinct symmetries, namely, continuous and discrete. Therefore, new guidelines are required for testing its commutation with the system Hamiltonian. One of the primary objectives of this study is to lay down these guidelines. Further, the possible impact of chiral symmetry on the geometrical arrangement of angular momentum vectors and investigation of observables unique to nuclear chiral-twins is carried out. In our model, the angular momentum components (J_1, J_2, J_3) occupy three mutually perpendicular axes of triaxial shape and represent a non-planar configuration. At certain threshold energy, the equation of motion in angular momentum develops a second order phase transition and as a result two distinct frames (i.e., the left- and right-handed) are formed. These left- and right-handed states correspond to a double well system and are related to each other through chiral operator. At this critical angular momentum, the centrifugal and Coriolis interactions lower the barrier in the double well system. The tunneling through the double well starts, which subsequently lifts the degeneracy among the rotational states. A detailed analysis of the behavior of rotational energies, spin-staggering, and the electromagnetic transition probabilities of the resulting twin-rotational bands is presented. The ensuing model results exhibit similarities with many observed features of the chiral-twins. An advantage of our formalism is that it is quite simple and it allows us to pinpoint the understanding of physical phenomenon which lead to chiral-twins in rotating systems.

Keywords: Nuclear structure; Triaxial particle–rotor model; Positive parity $\Delta I = 1$ chiral bands; Semiclassical approach

---

E-mail address: shammalik@yahoo.com.

http://dx.doi.org/10.1016/j.nuclphysa.2015.05.003

0375-9474/

1. Introduction

Chirality or handedness is commonly seen in the bio-molecules and it arises mainly due to the geometrical arrangement of atoms in a bio-molecule. It is, therefore, static in origin. Particle physics is another branch, where dynamic chirality prevails through the parallel and anti-parallel orientation of the spin with respect to the linear momentum of massless fermions. On the basis of these orientations, the anti-neutrino (right-handed) is clearly differentiated from the neutrino (left-handed). The occurrence of chirality in nuclear physics was first suggested in 1997 by Frauendorf and Meng [1] and is expected to occur in nuclei having triaxial shapes. Its dynamic character is supported by non-zero components of the total angular momentum along the three principal-axes of triaxially deformed nucleus.

Petrache et al. [2] have reported a pair of $\Delta I = 1$ bands with same parity in ^{134}Pr, which have been interpreted by Frauendorf and Meng [1] as a first candidate for chiral-twin bands. These bands arise mainly due to the possible existence of two enatiomeric (left- and right-handed) forms of the nucleus. Since then a large number of experimental investigations have been undertaken to establish the existence of chiral-twin bands in several mass regions of nuclear land scape [3–8]. It is emphasized that the observed doublet must have identical or, in practice, very similar rotational spectra, spin alignments, and electromagnetic transition probabilities.

The chiral-twin bands have been interpreted by using either the particle–rotor model (PRM) or the tilted-axis cranking (TAC) model for triaxially deformed nuclei [1,9–13]. The main point of both these models is that the total angular momentum vector that fixes the rotation axis, lies outside any of the three principal planes determined by the triaxial mass distribution. Two nearly degenerate $\Delta I = 1$ rotational bands with same parity originate from their left- and right-handed solutions. Although, these models have provided a reasonable description of the properties of chiral bands, however, some puzzling features are yet to be resolved. For instance, the description of quantum tunneling of chiral partners is not possible within the mean field approximation [14,15].

In order to describe the energy splitting between the chiral-twin bands, one has to go beyond the mean field approximation. Numerous efforts in this direction have already been carried out by various authors [12,13,16]. More recently, Chen and co-workers [17] have developed the collective model for explaining the prominent features of chiral-twin bands. They have established the collective Hamiltonian by extracting the potential energy and mass parameter from the TAC model. In their approach, they have realized for the first time an importance of the double-well potential in obtaining the chiral-twin bands. In analogy to collective model, the present work is dedicated to understand the features of chirality in rotating nuclei by using a simplified version of triaxial particle–rotor model in which the double-well potential appears at a certain threshold energy. This model yields directly the energy splitting by tunneling through the double-well potential. No free parameter is fitted to explain the experimental data.

The possible impact of the chiral symmetry on the geometrical arrangement of angular momentum vectors and investigation of observables unique to nuclear chirality is planned in our present study. In our model, the angular momentum components (J_1, J_2, J_3) occupy three mutually perpendicular axes of triaxial shape and represent a non-planar configuration. At critical angular momentum $I \geq I_{band}$, second order phase transition has arranged three components in such a way that two distinct frames (i.e., the left- and right-handed) are formed. These two enatiomeric states correspond to a double well system and are related to each other through chiral operator. The chiral operator $\hat{\chi} = \hat{R}_y(\pi)\hat{T}$ is a product of the time-reversal ($\hat{T}$) and rotation through 180° about the y-axis ($\hat{R}_y(\pi)$), and hence involve two distinct symmetries, i.e., discrete and continuous. Therefore, its selection rules are quite different from that of normal symmetries