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Deformation as a function of angular momentum inertia for the nuclei

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Abstract

The atomic nucleus is a one-of-a-kind system that contains both microscopic traits and statistical aspects. As a result, it is possible to collect a substantial quantity of information about nuclear parameters at high excitation energy and angular momentum from the nucleus of the atom. It has been discovered that statistical representations of many-body quantum systems are quite frequent in the body of literature that focuses on the characteristics of nuclei that are connected with limited temperatures. This is the case when the literature is studied from a theoretical point of view. Over the course of the past few years, the improved experimental techniques that are available in the field of heavy ion physics have also been a driving factor behind the stimulation of research on highly excited nuclei that are formed in experiments that include heavy ion fusion processes.

Keywords: Atomic nucleus, high excitation energy

Introduction

Effects of rotation

The capacity of nuclear theory to explain why a nucleus may adopt a variety of forms and even to anticipate where on the nuclear chart these varied shapes would appear is one of the more significant achievements of this field of study. The vast array of forms that may be found in atomic nuclei is a topic that continues to be the focus of study that is both dynamic and quickly developing. After the use of rapid rotation as a novel instrument for the examination of nuclear forms, a substantial amount of experimental and theoretical knowledge on the structure of the nuclear material in high spin states has been accumulated. Because of the introduction of greatly improved technological capabilities, such as the gamma ray detectors of the most recent generation, this study field has experienced a meteoric rise in recent years. In addition to this, the availability of faster computers has made it feasible to conduct realistic theoretical studies with huge configuration spaces. This has also made it possible to analyse nuclear structural changes in the full mass region in a more transparent manner. In order to investigate the morphology of hot spinning nuclei, measurements of giant dipole resonance constructed on excited states, alpha-gamma angular correlations, rotational damping, and other related phenomena are being carried out among other things. We undertake the study of the thermal and rotational response to nuclear properties, particularly the phase transitions and shape evolution, by means of a statistical framework. However, experiments indicate that a quantitative estimate of the persistence of ground state deformation with temperature may be missing in some cases. As a result, we undertake this study.

Population of high spin states

There are a number of different approaches that may be utilized in order to accomplish the task of filling the rapidly spinning nucleus in a state of high excitation energy. The heavy ion fusion evaporation process is the most popular of these approaches. In a process that is referred to as complete fusion evaporation, the nucleus of the projectile, which contains a considerable amount of kinetic energy and angular momentum, fuses with the nucleus of the target, which ultimately results in the production of a fused composite system. Following the emission of the particles, the nucleus that is left behind after the emission possesses a higher angular momentum and a higher excitation energy than it had before the emission. Following the entrance state, which is the state in which the nucleus is related to particle emission, the

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seven rays are responsible for cooling the nucleus that is left over after the entry state. The term "entry state" is used to refer to this particular condition. The gamma rays that are produced by the transitions between the levels that are on or near the yrast line have been the subject of a significant amount of study from the researchers.

Nuclei at high spin states

Heavy ion beams are used in order to bring in sufficient angular momentum for the purpose of investigating high spin states in nuclei. This is done in order to accomplish the goal of studying high spin states. Furthermore, there are two basic methods in which the atomic nucleus is able to generate spin or rotational momentum.

- Through the process of matching the spin vectors of the different nucleons, this ends up producing an uneven nuclear level structure in the case of weakly deformed nuclei that are close to being spherical
- This results in a regular level structure for nuclei that have been properly distorted, and it is accomplished by the process of collective rotation along an axis that is perpendicular to the axis of nuclear symmetry.
- The vast majority of states are, on average, a blend of these two extreme modes. This is the case in the majority of situations. It has been observed that the extremely high spin states that are present in nuclei exhibit a wonderful range of events and symmetries as a result of their presence. An overview of some of the events that have taken place is presented below in a brief conversation.

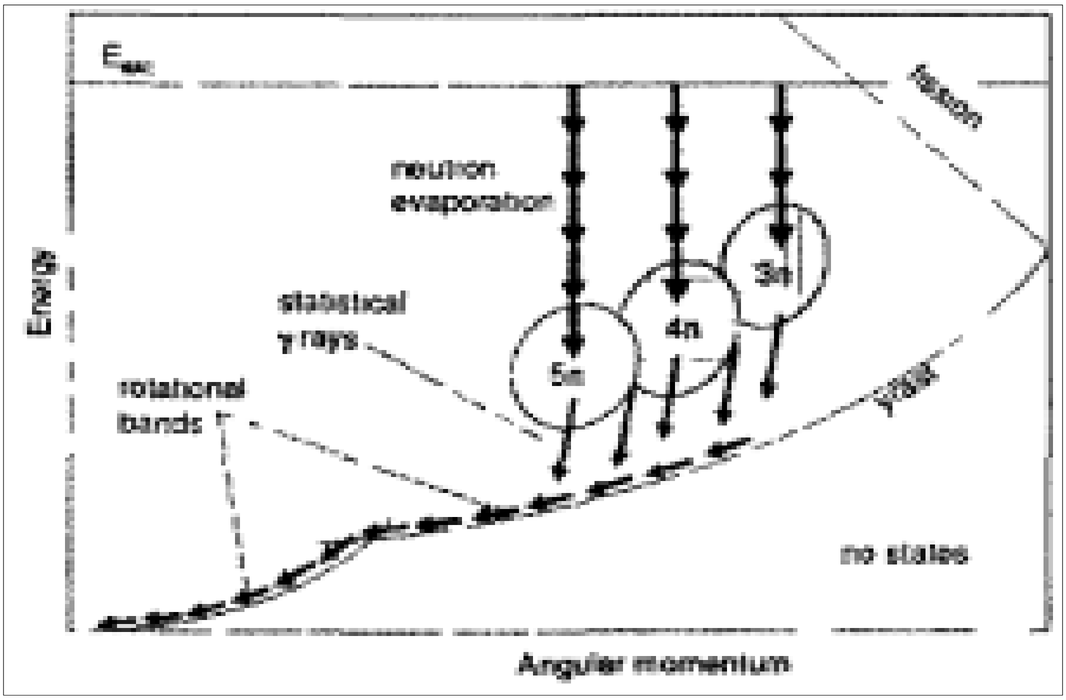

Fig 1: Illustration of the many channels that supply the yrast states in a schematic configuration

Yrast line

The use of the yrast line allows for the establishment of a link between the states that possess the least amount of energy for each angular momentum value. Therefore, there are no states that are situated below this line in the United States. It is conceivable to examine new types of phenomena that are situated above the yrast line and go higher in energy and temperature. This is something that can be performed. Some examples of events that can take place include phase transitions, quasi-continuum and rotational damping, enormous resonances, the melting of shell structure, and the transition from order to chaos. Others include the melting of shell structure.

Reduction of pairing correlations with rotation

When nuclear super fluidity is subjected to high rotational frequencies, there is a potential that it will be entirely collapsed or quenched. This is a possibility. The angular momentum acts in a manner that is comparable to that of an external magnetic field, and as a result, it makes an attempt to align the angular moments of individual particles along the axis of rotation. As a consequence of this, correlations between nucleonic Cooper pairs are destroyed during the process.

Identical band

There is a sequence of ten or more photons that are similar to one another and are coupled with unique bands in nuclei that are next to one another. The sequences in question are referred to as identical bands. This comes as a significant surprise. It was not anticipated. Since the beginning of time, humans have been under the impression that the gamma ray emission spectrum of a specific nucleus is a fingerprint that is entirely exclusive to that nucleus. If there is a cohesive theoretical explanation for these patterns in a wide variety of nuclei, it has not yet been determined whether or not there is such an explanation.

Super deformation

In specifically, super deformation occurs in nuclei when quantum shell processes contribute to the stabilization of a football-shaped structure with a ratio of 2:1 axis to axis. This gives rise to the phenomenon known as super deformation. Researchers have discovered a variety of spots within nuclei that are distinguished by the existence of this distinctive second minimum in their potential energy landscape. These areas have been found throughout the course of their research. Super deformed nuclei have been shown to exhibit a wide array of remarkable characteristics, according to the findings of researchers. For the purpose of gaining a deeper knowledge of particular orbits over the Fermi surface, it is feasible to get this insight by examining a variety of properties of super deformed nuclei, the underlying shell structure of the observed mass region, and the high neutron scheme.

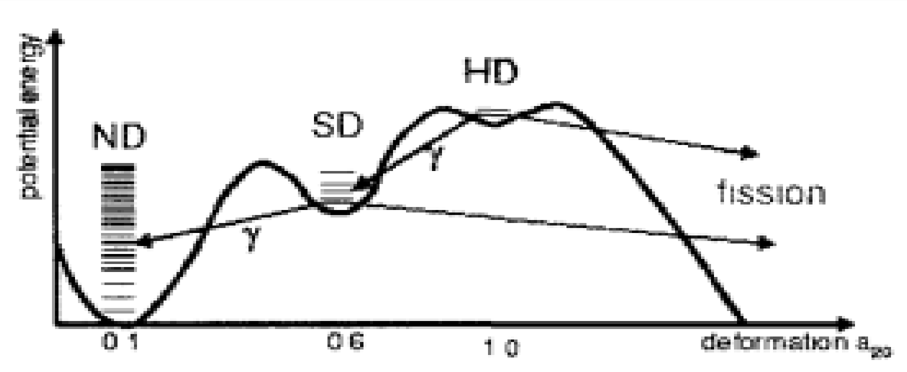

Fig 2: A chart that compares the potential energy to the deformation

Hyper deformation

A number of various models have predicted that hyper deformation will take place, and these objects have an odd third minimum in their potential energy landscape, which can be shown in Figure 2. This is something that has been expected by a number of different experiments. It is projected that very elongated nuclear forms with an axis ratio of at least three to one will take place when the nuclear states are at their most unstable. This happens when the nuclear states are at their most unstable. There have been several attempts made to produce and observe these states; nevertheless, the studies that have been carried out up to this point have not been sufficient.

Band termination

The gradual shape shift that is brought about by angular momentum is what ultimately leads to the end of the band. This transition takes place from a state of collective rotation that has been distorted to a configuration that is not collective and is entirely prohibited from rotating in accordance with quantum physics. It has been noticed that a number of nuclei have undergone a demise of the spinning band, which implies the basis of the nuclear multi-fermium system being composed of limited particles.

Magnetic rotation

Magnetic rotation is a phenomenon that occurs in approximately spherical nuclei and is described by sequences of gamma rays that are suggestive of collective rotating bands. This phenomenon is differentiated from other types of rotation. On the other hand, the features of magnetic rotation are significantly different from one another. To be more specific, each photon only takes only one unit of angular momentum, as opposed to two units, and relates to the magnetic characteristics of the nucleons rather than the electric properties. In this particular instance, the quantum rotor in issue is a new form that has not been observed in a way that is both clear and transparent. It is still not possible to have a complete and correct knowledge of each and every one of these situations. This thesis is centered on the investigation of the microscopic characteristics of phase transitions and shape deformations, with a particular emphasis on the interaction between spherical, deformed, and super deformed (SD) forms. The ultimate objective of this thesis is to acquire a comprehensive understanding of the phenomena that are associated with these shapes.

Moment of Inertia

A large amount of change and mixing occurs in the orbitals of single particles that are contained within the nucleus as a result of the fast rotation of the nucleus. A single number, known as the nuclear moment of inertia, is responsible for determining the majority of the relationship between the sequence of energy levels and the distances that separate them in the spinning band. The influence that high angular momentum has on the structure and deformation of nuclei has been the subject of a number of research that have been carried out concerning the link between the shape of energy and spin. These studies have supplied a great lot of information regarding this relationship. When the nucleus is allowed to rotate, it has been shown that the moment of inertia does, in fact, change depending on the spin orientation of the nucleus. It is possible to examine the rotational energy spectrum of a spinning nucleus in terms of two spin-dependent moments of inertia, which were described by Bohr and Mottelson. This is because of the fact that the nucleus is spinning. There is a connection between these moments of inertia and first-order (j^) and second-order degrees of freedom and derivatives of their second order (, /2 ') about the energy of excitation in relation to the aligned angular momentum (I) system- The phenomenon known as back bending is an example of the structural changes that might take place in a nucleus while it is rotating. Despite the fact that it was discovered a few decades ago, the sudden increase of a nuclear moment of inertia in the yrast rotational band at a crucial angular momentum or rotational frequency continues to attract a significant amount of interest. The rotational alignment of angular momenta of a nucleon pair that is occupying a high-j intruder orbital near to the Fermi surface is assumed to be the origin of this event, according to a general theory. This hypothesis was developed to explain the explanation of this phenomenon. The moment of inertia in a classical rotor is not only influenced by the geometry of the rotor, but it is also determined by the flow pattern of the materials that are involved. In order to precisely describe a substantial number of the low-lying levels that are present in a circular band, a nucleus that has a constant moment of inertia (j) is utilized. When, on the other hand, the spin is high, the value of j will be greatly increased during the course of the experiment. There is a possibility that the smaller value of j is a reflection of a more severe deformation or of a considerable decline in the number of nucleons that have been paired off. Both of these possibilities are feasible. Indirect evidence for an energy gap that is produced by pairing is provided by the impact of j. This evidence is supplied as a piece of evidence.

Pairing

The structural changes that may occur in a nucleus while it is rotating include the phenomena known as back bending, which is an example of one of these alterations. The abrupt rise of a nuclear moment of inertia in the yrast rotational band at a vital angular momentum or rotational frequency continues to attract a large amount of interest, despite the fact that it was found a few decades ago. Rotational frequency is a crucial factor in determining the angular momentum. According to a general theory, the genesis of this event is supposed to be the rotational alignment of angular momenta of a nucleon pair that is occupying a high-j invader orbital close to the Fermi surface. This is the assumption that is made about the origin of this event. The purpose of developing this theory was to provide an explanation for the phenomena that was seen. Not only does the geometry of the rotor have an effect on the moment of inertia in a classical rotor, but the flow pattern of the materials that are involved also plays a role in determining the moment of inertia. It is necessary to make use of a nucleus that possesses a constant moment of inertia (j) in order to accurately represent a significant number of the low-lying levels that are present in a circular band. On the other hand, if the spin is high, the value of j will significantly grow during the length of the experiment. This will occur when the spin is high. There is a chance that the decreased value of j is a reflection of a more severe deformation or of a significant decrease in the number of nucleons that have been paired off. Both of these possibilities are possible. These two ideas are both reasonable to consider. The effect of j is a piece of evidence that provides indirect evidence for the existence of an energy gap that is caused by pairing. As a piece of evidence, this evidence is available to be presented.

Effects of pairing correlation

The alteration of the structural properties of the nuclei brought about by the presence of paired interaction is the outcome of this interaction. Therefore, this is due to the fact that pairing contact has the potential to supply the nuclei with extra binding force. Under the influence of this force, the nucleons continue to scatter with their paired counterparts. The degree to which they do so is dependent on the availability of vacant orbits in the neighborhood of the Fermi surface if they are to continue to scatter. As a consequence of this, the unoccupied orbits are also a significant component in the dynamics of the nuclear system. A single particle's energy level that is placed above the Fermi surface acts more like a particle state, whereas the energy level that is located below it behaves more like a hole state. This is because the Fermi surface is the boundary between the two types of states. This leads to the production of quasi-particle states, also known as orbits. These orbits are a mixture of particle states and hole states that are situated in close proximity to the Fermi surface. There is a distinction between these states and pure particle states, which are situated above the Fermi level, and pure hole states, which are situated below the Fermi level. The solutions of the entire nuclear Hamiltonian, which take into account the pairing interaction, are represented by these states. Consequently, the moment of inertia is decreased as a consequence of these correlations in contrast to the value of the rigid rotor, and the nucleus is regarded to be in the super fluid phase as a result of this.

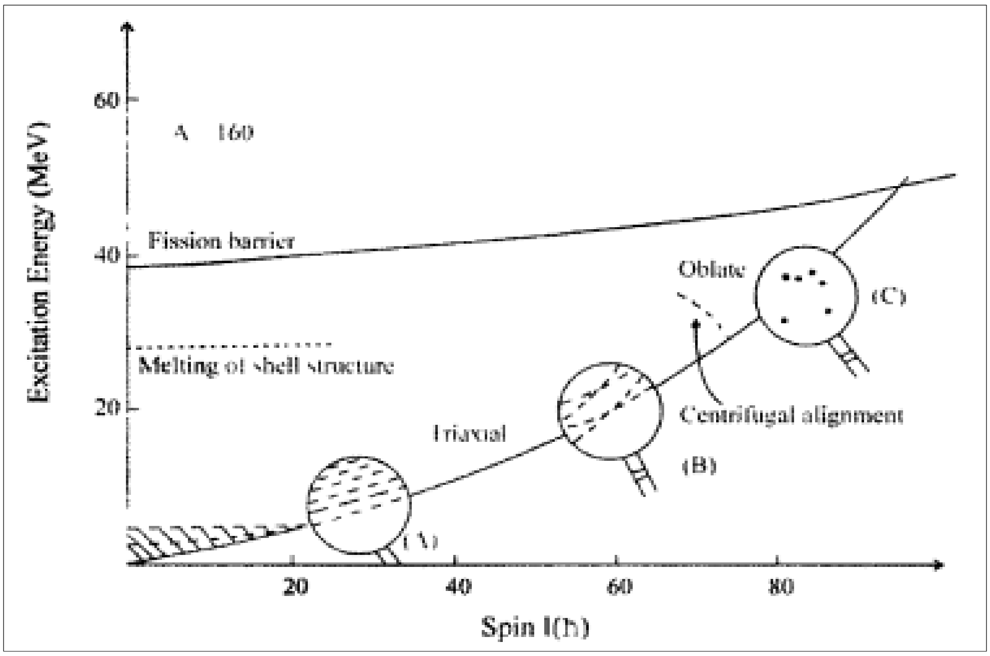

Fig 3: The phase transitions of nuclear particles as a function of the rotational momentum and the excitation energy

Objectives

To find the Deformation as a Function of Angular Momentum Inertia for the Nuclei

Research methodology

He took a single-particle potential that was based on a deformed harmonic-oscillator potential and modified it by a strong spin-orbit (l. s) force and a (l2-< l2 >N) term to simulate the flattening of the potential at the center of the nucleus. This was the first deformed potential to describe axially symmetric nuclei. Nilsson was the first person to introduce this concept. Furthermore, a deformed Woods-Saxon potential is an additional distorted single-particle potential that is frequently utilized. In the case of deformed nuclei, the nuclear radius can be parameterized in terms of a multi pole expansion given the assumption that the nuclear volume remains constant.

$$R(\theta(\varphi) = c(\alpha)R_0\left[1+\sum_{\lambda=2}^{\lambda_{max}}\sum_{\mu=-\lambda}^{\mu=\lambda}\alpha\lambda_{\mu}Y_{\lambda\mu}(\theta,\varphi)\right] \quad (1)$$

The expansion coefficients of the spherical harmonics Y^{γ} are denoted by the symbol¸. These coefficients define the surface coordinates as functions of and, respectively. R0 represents the radius of a sphere that has the same volume as the nucleus. When the volume-conservation requirement is fulfilled, the parameters c are taken into consideration. The quadrupole deformation corresponds to the =2 multipole, which is the lowest multipole. For axially-symmetric structures, the coefficients that are not equal to zero are eliminated, and as a result, the nuclear radius can be expressed as follows.

$$R(\theta(\varphi) = c(\alpha)R_0[1+\beta_2 Y_{20}(\theta\theta\varphi) \quad (2)$$

In fact, it is not reliant on the value of ^{R}. Quantifying the nuclear deformation is accomplished by the quadrupole deformation parameter β2, where α is equal to 20. The higher the value of β2, the more distorted the nucleus remains. The forms of prolate and oblate are corresponding to the values of β 2 that are positive and negative, respectively. Due to the fact that quadrupole deformations might result in the development of asymmetric forms through the use of triaxial distortions, it is necessary to utilize extra shape factors. One way to characterize the stretching and squashing impact that occurs at right angles to the primary nuclear axis is through the form degree of freedom. A appropriate shell model scheme that is developed for a variety of nuclear deformations should be considered the fundamental component of the theory. The many parameters that are involved in the deformed harmonic oscillator Hamiltonian for hot spinning nuclei have received a significant amount of research. Cranked oscillator levels and triaxially deformed single particle levels are the subjects of investigation in this chapter of the thesis, which is devoted to the examination of the methods that are available to generate these levels.

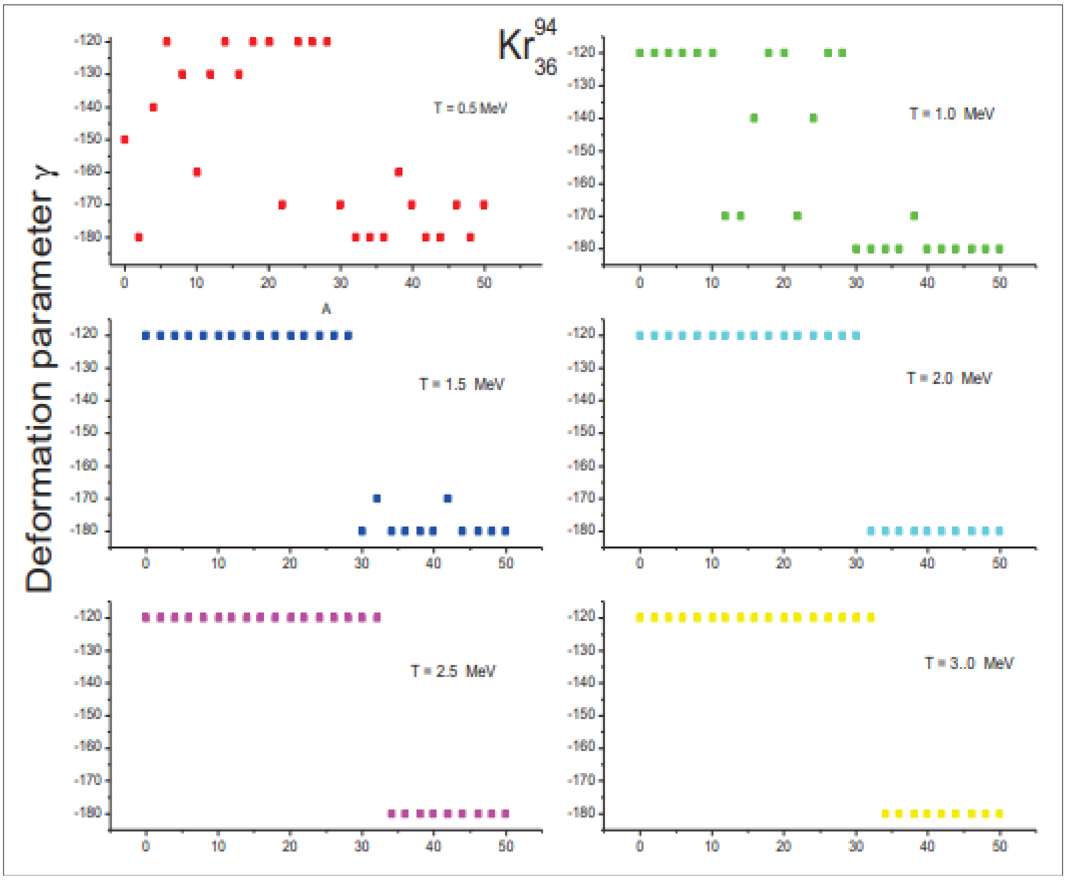

Fig 4: The deformation as a function of angular momentum I for the nuclei 94Kr

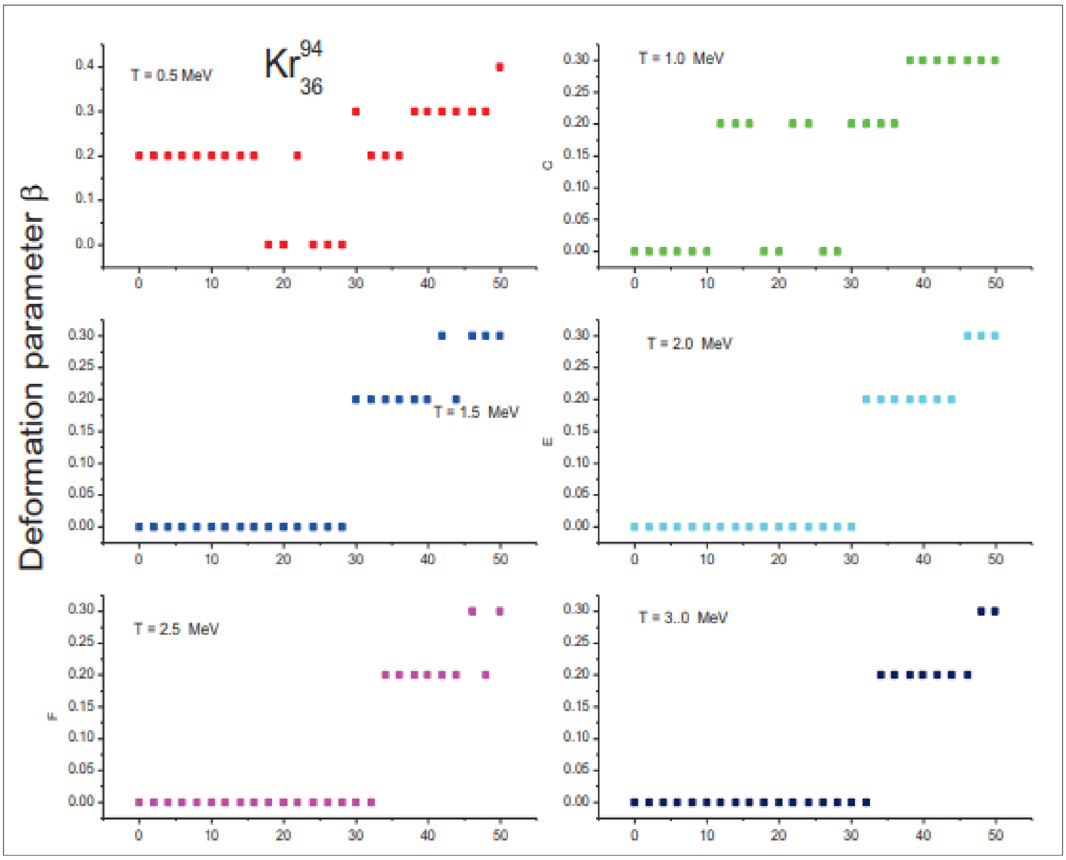

Fig 5: The deformation as a function of angular momentum I for the nuclei 94Kr

The form history of the 100 Mo nuclei is depicted in this evolution is shown as a function of angular momentum at as many temperatures as possible. At a temperature of T = 0.5 MeV, minor tri-axial deformations begin to take place gradually as the angular momentum increases Using it is discovered that when the spin is low, the nucleus takes on a prolate collective form. This is the case with the 100Mo nuclei. The tri-axial structure is achieved by a seamless transition when the spin is increased. At the temperature T = 1.0 MeV, the nucleus displays a behavior that is analogous to the one described above. As the temperature rises, the existence of tri-axial form disappears, and the nuclei go through a shape transition from collective prolate to non-collective oblate shape. This is an intriguing phenomenon to observe. Through the use of plot the impact that is brought about by phase variations with T may be viewed more clearly. It is clear from looking at that the nuclei 100Mo and 102Mo exhibited transitional trend patterns that were comparable to one another.

Results

Today, one of the most significant areas of research in the field of nuclear physics is the study of nuclear structure at high excitation energy, sometimes known as "hot nuclei." Over the course of the past several decades, there has been a significant amount of interest demonstrated in the examination of structural transitions of highly excited nuclei as a function of both the angular momentum and the temperature. Heavy ion fusion reactions result in the formation of a composite nucleus that is both hot and fast revolving. The relative kinetic energy of the colliding nuclei is transferred into the internal excitation energy and high angular momentum of the compound nuclei during heavy ion fusion processes, which results in the formation of hot nuclei. In spite of the fact that the system has been cooled down by the emission of neutrons, the compound nucleus continues to maintain high angular momenta and moderate thermal energy. It is typically anticipated that nuclei that are both hot and spinning will display a wide range of various forms. As a result of the beginning of deformation in the neutron-rich nuclei, there is a significant amount of interest in the investigation of the structure of nuclei in the mass area A 100. These neutron-rich nuclei are of particular interest due to the fact that they are located on the boundary between a rather spherical shape and a shape that has been distorted significantly. The region has been investigated theoretically through the utilization of the interacting Boson model, the Nilsson Strutinsky Cranking method statistical theory, and the Hartree-Fock-Bogolyubov analysis.

The practical and theoretical features of transitional nuclei in the neutron-rich A~100 have been subjected to significant and comprehensive study over the course of the past several decades. It has been noted that the most fast growth of deformation has occurred in this particular section of the nuclear chart. Once a small number of neutrons or protons are introduced, a fast transition takes place from a spherical shape to a well-deformed ground state shape around the number N~60. The majority of these techniques relate to cold nuclei and are only suitable to yrast spectroscopy, to speak in a strictly literal sense. The nuclear shape at high excitation energy has not been investigated in these studies, and the statistical features of rapidly spinning nuclei have not been taken into consideration in the appropriate manner.

Conclusion

In this chapter, we provide the conclusions that were drawn from the data that were presented in the chapters that came before it, as well as what it has contributed to our comprehension of the structural alterations and form transition that have occurred in the light A^100 region. By employing statistical theory, we have conducted an investigation into the structure of nuclei, namely in the A^100 area. The following values of angular momentum were investigated: 94Kr, 96Kr, 98Kr, 98Zr100Zr, 102Zr, 100Mo, 102Mo, and 104Mo. The shape changes that occurred for these values were analyzed. It has been discovered that when the spin is low, the nucleus takes on a non-collective form that is oblate. The tri-axial structure is achieved by a seamless transition when the spin is increased. At a temperature of 1.0 MeV, the nucleus displays a behavior that is analogous to the one described above. As the temperature rises, the presence of tri-axial form disappears, and the nuclei go through a shape transition from collective prolate to oblate shape. This is an intriguing phenomenon to observe.

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