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Nuclear Shape Changesin Odd-A Promethium Isotopes (Pm)

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ABSTRACT

We have developed a special computing code for calculation of nuclear shape changes and quadrupole moments (Q) of Promethium Isotopes. It has been shown from these calculations that by increasing neutron number, deformation parameter also increase for more heavier isotopes which means more deformation from spherical shape. By comparison with Nilsson level energy diagrams we can infer quadrupole deformation parameter (β_2) and hence calculate quadrupole moments of these isotopes.

Keywords: Yrast states, Backbending, Deformation parameter, Quadrupole moment, Shape change

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1. INTRODUCTION

We know that nuclei in many cases have large quadrupole moments (Q) and they don't behave like a point charge, rather a spherical or elliptical shape with an axis of symmetry is considered for these nuclei. By knowing the quadrupole moments, we can measure deformation parameters which can be used to define the shape of nuclei. There are different theoretical and experimental methods for calculation and measurement of nuclear electric quadrupole moments [1-7].

In this paper we present a new method for calculation of quadrupole moments of odd-A Promethium isotopes. By study of rotational gamma-decay cascades in different bands of these isotopes and drawing the experimental yrast level energies versus moments of inertia for each band, we look for Backbending phenomenon [8] for each Pm isotope. If there is a Backbending, then it means that there is a change of moment of inertia,which is happening by excitation of a nucleon to another state with different angular momentum. Thus changing the total spin of nucleus. By comparison with related Nilsson diagram [9], we can find the location of displaced nucleon and thus find the related quadrupole deformation parameter (β_2) at that excitation energy. By finding the deformation parameter we can calculate the quadrupole moment of the deformed isotope and study shape changes.

1. Theoretical Calculation and Discussion

Nuclei can be obtained in very high angular momentum states, mainly through heavy-ion induced reactions (HI, xn). The states that are populated subsequently, decay, through a series of statistical low-spin transitions, into the high-spin lower energies yrast structure .

It has been shown that a large amount of angular momenta can be obtained by collective motion (i.e. a coherent contribution of many nucleons to the rotational motion). It is important that the nucleus exhibits a stable, deformed shape. Subsequently, rigid rotation will contribute angular momentum Jand energy E according to the expression

$$E = \frac{\hbar^2}{2\mathcal{I}} I(I+1) \qquad (1)$$

Where I is the moment of inertia.

Besides the collective rotational motion, angular momentum can be acquired by non-collective motion. Here, the alignment of the individual nuclear orbits along the nuclear symmetry axis contributes to the total nuclear spin. The system does not have large deformed shapes but remains basically spherical or weakly deformed.

The excited states should cascade down toward the ground state through a sequence of E_2 gamma transitions. The observation of these cascade E_2 transitions provides a way to study these excited states. In particular, we can study whether the assumption of a fixed constant moment of inertia remains valid at such high excitations. One way to test this assumption is to plot the energies of the states against I(I + 1) and to see if the slope remains constant. Figure 1 is an example of such a plot for ^{158}Er and ^{174}Hf nuclei and as it can be seen there appears to be some deviation from the expected linear behavior[8].

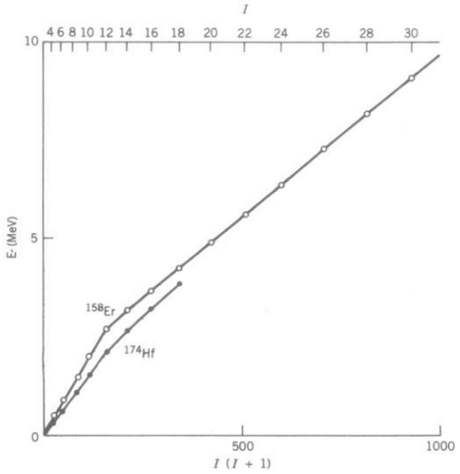

Fig 1. E versus I(I + 1) plot for Er and Hf nuclei[8].

If we assume that the moment of inertia is not constant but increases gradually as we go to more rapidly rotating states. This effect known classically as "centrifugal stretching" would not occur for a rigid rotor but would occur for a fluid. Because rotating nuclei have moments of inertia somewhere between that of a rigid rotor and of a fluid, it is not surprising that centrifugal stretching occurs. There is a more instructive way to plot the data on the rotational structure. From equation (1) the energy of a transition from state I to the next lower state I -2 is

$$E(I) - E(I-2) = \frac{\hbar^2}{2\mathcal{J}}(4I-2) \qquad (2)$$

Or by rearranging the terms

$$\frac{2\mathcal{J}}{\hbar^2} = \frac{4I-2}{E(I)-E(I-2)} \qquad (3)$$

By plotting the left hand side of the above equation versus the square of rotational frequency ω^2 , there appears to be a gradual increase in moment of inertia among the lower angular momentum states, then a radical change in behavior and then again a return to the gradual stretching as shown in figure 2. This effect which is known as Backbending occurs in some heavy nuclei because the rotational energy exceeds the energy needed to break a pair of coupled nucleons. When this effect occurs, the unpaired nucleons go into different orbits and change the nuclear moment of inertia [8].

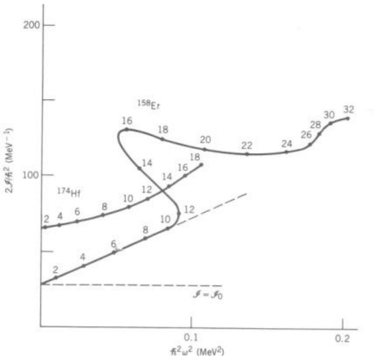

Fig. 2 Moment of inertia versus ω^2 showing Backbending[8].

2. Shape Changes in Promethium Isotopes

Promethium Isotopes have 61 protons. In this paper we studied rotational gamma decays of Isotopes from A=129 to A= 157. Figure 3 clearly shows Backbending for A=135 Isotope. Using this plot and comparison with Nilsson diagram for neutrons with N = 74, we find quadrupole deformation parameter for this isotope β_2= -0.01. From this finding and using the Grodzinsformula for quadrupole moment[10]

$$Q \cong \frac{3}{\sqrt{5\pi}} Zr_0{}^2 A^{\frac{2}{3}} \beta_2 \qquad (4)$$

We can calculate the quadrupole moment, which is a measure of deformation of nucleus from spherical shape.The changes in deformations and calculated quadrupole moments for odd-A Promethium isotopes are summarized in table 1.

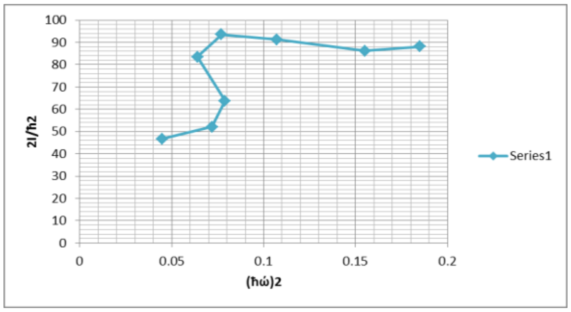

Fig 3.Backbending for A=135Promethium isotope.

Mass Number (A)	Deformation Parameter (β_2)	Quadrupole Moment (Q2)
129	0.22	374.36
131	-0.052	-93.35
133	-0.031	-55.47
135	-0.01	-57.60
139	0.37	710.11
141	0.28	517.41
143	0.42	828.46
145	0.26	505.25
147	0.28	541.89
149	0.34	680.85
151	0.38	772.71
153	0.073	142.79
155	0.18	361.26
157	0.22	447.76

Table 1. Deformation parameters and Quadrupole moments for Promethium isotopes

As it can be seen from the above table, with increasing neutron numbers in Promethium isotopes, changes in shape occur from oblate (negative Q.M) to prolate (positive Q.M). With the exception of A= 153 and 155, the quadrupole moments are quite high which means more deformation from spherical shape. These exceptions may be due to passing shell closure at N=82.

2. CONCLUSIONS

It has been shown from these calculations that by increasing neutron number of Promethium isotopes, deformation parameter also increase for more heavier isotopes which means more deformation from spherical shape. By comparison with Nilsson level diagrams we can infer deformation parameter (β_2) and calculate quadrupole moments of these isotopes. This means that there are shape changes from oblate to prolate deformations in these isotopes. With the exception of A= 153 and 155, the quadrupole moments are quite high which means more deformation from spherical shape. These exceptions may be due to passing shell closure at N=82.

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