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Study of the strength distribution of primary γ-transitions in the decay from superdeformed states in ^{194}Hg

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The strength distribution of the primary γ rays in the decay from superdeformed (SD) states is investigated by applying the maximum likelihood method. For the ^{194}Hg nucleus, 41 primary transitions are identified above 2600 keV. It is concluded that they represent the strongest 10% of the transitions selected stochastically from a Porter-Thomas distribution. This would support the scenario of a statistical decay of SD states via coupling to a compound state at normal deformation. However, the occurrence of several very strong "one-step linking" transitions is found to have a very small probability. Based on the absence of strong primary transitions from SD states in adjacent nuclei, the situation in ^{194}Hg is viewed as a very lucky incidence.

1. INTRODUCTION

Due to large shell gaps, secondary minima in the potential energy surface of a nucleus can appear at large deformation, and in particular at superdeformation. The SD minimum becomes the principal minimum of the nucleus at high spin, this is why, one needs to produce the nucleus at high angular momentum where it has a chance to be trapped in the SD minimum. Rapidly spinning nuclei are usually formed in fusion-evaporation reactions. The hot and rapidly-rotating compound nucleus cools by evaporating light particles, then γ-rays. In the very rare case where the nucleus goes through a SD stage before reaching its quasi-spherical ground-state, first come transitions from thermally excited states at rapid rotation. Then follows a chain of up to $\sim$ 20 transitions, regularly spaced in energy. These form the well known SD rotational band. At low spin, the band very suddenly terminates when the nucleus changes shape and decays to ND states. From lifetime measurements, one knows that the potential barrier separating the SD states from the neighbouring ND states still exists at the point of decay, therefore, the decay from SD states in the mass A=190 region must proceed via tunneling through the barrier.

2. DECAY SCENARII

The tunneling proceeds as a motion in collective coordinate space. If the excitation energy U of the decaying SD states is such that the motion on the ND side stays within collective degrees of freedom, the tunneling will manifest itself as an admixture into the SD state of ND vibrational states. The decay from SD states is then due, for example, to the quadrupole coupling between the tail of the SD wavefunction in the first well and the wavefunctions of lower-lying ND vibrational states. This is successfully described in the GCM approach [1]. On the other hand, if U is large enough, the collective states on the ND side will be thoroughly mixed into a dense background of very complicated multi particle-hole states. In the weak coupling limit, the tunneling will manifest itself as an admixture into the SD state of one of these compound states [2]. The decay of SD states is then due to the statitical coupling between the tail of the SD wavefunction in the first well and the wavefunctions of lower-lying ND states. The question is : *does the decay from SD states occur in the ordered regime or in the chaotic regime, or somewhere in between ?* In order to answer this question, one has to examine the decay spectrum in detail.

In mass A=190 nuclei, the decay spectrum comprises a quasicontinuum on which are superimposed a few discrete lines [3] (see figure1). In the case of ^{194}Hg, very high-energy

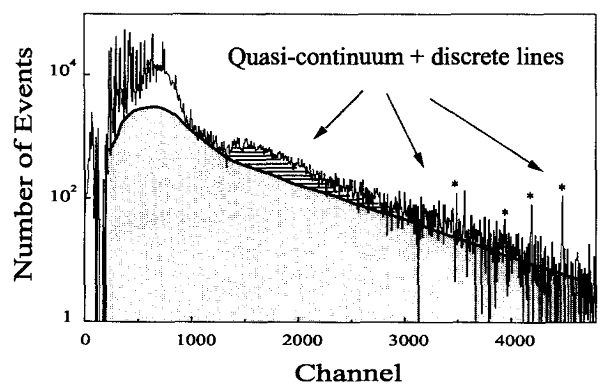

Figure 1. Spectrum of γ-rays emitted by the superdeformed ^{194}Hg nucleus.

γ-rays directly conecting the decaying SD states to known ND yrast states could be observed [4]. Thanks to these "one-step linking" transitions (marked by a star), we know that the excitation energy of the SD 10^+ state is large: 4.2 MeV above the ND yrast 10^+ state. From a fluctuation analysis similar to that performed in reference [5], we know that the fragmentation of the decay is large: of the order of 10^4 transitions are sampled in the decay.

From the behaviour of the distribution of sampled transitions as a function of their energy, we also know that the decay from SD states in ^{194}Hg most probably occurs in the weak coupling limit. A statistical decay spectrum calculated in a very schematic model including pairing reproduces the main features of the decay spectrum [6]. Finally, Teng Lek Khoo and collaborators compared the decay spectrum in ^{194}Hg to that obtained following thermal neutron capture in ^{167}Er. Both spectra show the same features which are typical of the decay from a hot state. All the information given above constitutes strong evidence that *the decay from SD states is mediated by an admixture of a compound state.*

However, compared to the situation at the neutron resonances, where such a compound statistical character is firmly established [7,8], the decay from SD states occurs at lower excitation energy and is initiated by a tunneling process. Therefore, it cannot be taken for granted that the same chaotic behaviour is encountered in the decay from SD states.

The hallmark of a purely statistical decay from a compound state is the Porter-Thomas distribution of strengths [9] which is a χ^2 distribution with $\nu = 1$ degree of freedom. It favours very weak strengths but has a tail that extends to very large strengths. This yields larger strength fluctuations than other χ^2 distributions. This might explain the differences observed in the high-energy part of the decay spectrum in ^{192}Hg and ^{194}Hg. These nuclei are very similar in many respect, yet one shows strong peaks at high energy and the other not. *Are the differences related to some structural effect, or are they just due to an accidental enhancement of random matrix elements* ? To find out, one needs to determine the nature of the primary-transition strength distribution in ^{194}Hg.

3. ANALYSIS OF PRIMARY-TRANSITION STRENGTHS

The data available for this nucleus consist of 2 high-statistics Gammasphere experiments. Since the average excitation energy of the SD states at the point of decay is ~ 4.2 MeV the most intense transitions with energy well above half this value may be assumed to be primary γ-rays. In total, 41 such lines are identified above 2.6 MeV, but only 31 stand out from the noise of the spectrum. Primary transitions following neutron capture have been shown to have a ratio of $E1/M1$ strength of 5-7. On this basis, we have assumed that all the primary decay transitions in ^{194}Hg have $E1$ character. The relative strengths w_i are given by this expression:

$$w_i = I_i \times \left(\frac{E_0}{E_i}\right)^3 \tag{1}$$

I_i is the intensity of the transition i in units of multiplicity, E_i, its energy, and E_0 an average transition energy. One then defines the experimental strength threshold, w_{low}, above which it is certain that no line has been missed. What one seeks are the parameters ν (number of degrees of freedom) and θ (average relative strength) of the χ^2 distribution which is most likely to describe the experimental set of strengths above w_{low}. We do this by means of the *Maximum Likelihood Method* and by assuming that the relative strengths from the two initial states (the 10^+ and 12^+ SD states) are selected from a common χ^2 distribution. In total, 19 strengths lie above w_{low}. The most likely χ^2 is found to be a Porter-Thomas distribution: $\nu = 1^{+20}_{-1}$ [10]. This result is illustrated in figure2. From a fluctuation analysis performed in the 2.6-5 MeV interval, one knows that there are ~600 primary transitions in that energy range. The value of the most likely cumulative strength distribution at the origin gives an alternative estimate: 400. Dividing the total relative strength, obtained in a quasicontinuum analysis, by the average, θ, gives yet another estimate: 550. All these independent numbers agree very nicely. However, the error bar on the number of degrees of freedom of the most likely distribution is large. This is because experimentally, one can only access the tail of the strength distribution (the 19 strongest lines out of a total of 600!) and it is only at low strength that the different χ^2 distributions really differ.

Assuming that the strength distribution is Porter-Thomas, the probability to have a strength 8 times greater than the average is somewhere between 1/100 and 1/330. So one should expect 2-6 very strong lines. Experimentally, there are 3 such lines. So it seems again that everything fits. However, 2 of these strong lines are "one-step linking" transitions. It is very unlikely that such large strengths should have been selected for this particular type of transition. One would then be inclined to say that this might be the sign of some selection rules at play. However, faced with the question: "what feature distinguishes the SD states in ^{194}Hg from those in ^{192}Hg ?", we have no answer, and so we must conclude that *the occurrence of strong one-step links in ^{194}Hg represents a lucky case.*

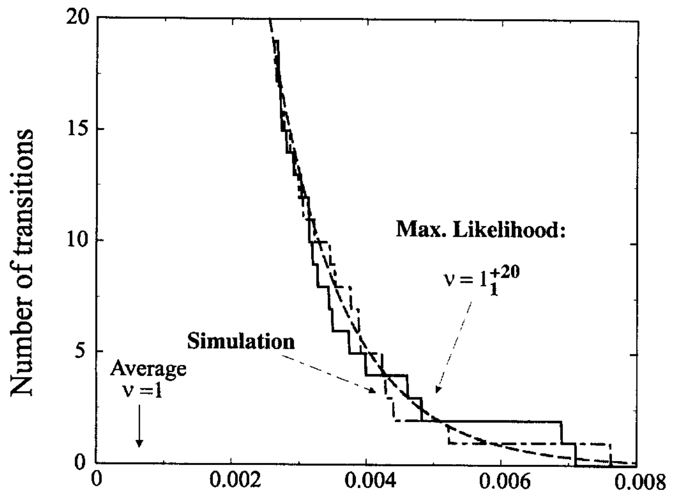

Figure 2. Plot of the experimental cumulative strength distribution (thick solid line), of the most likely cumulative distribution (long dashed line) and of the cumulative strength distribution of a set of 19 strengths which result from random sampling of a Porter-Thomas distribution above w_{low} (dotted-dashed line). The arrow indicates the value of the most likely average strength θ.

4. CONCLUSION

In conclusion, it seems that the decay from SD states in ^{194}Hg might be statistical and that the presence of strong "one-step links" is just the luck of the draw. However, one must keep in mind that the Maximum Likelihood results have large error bars, and that for ^{194}Hg, one will probably have to wait for the next generation of γ arrays in order to conclude with more certainty. ^{194}Pb, on the other hand, is a more favourable case to study with the present arrays. The excitation energy of the SD states at the point of decay is much lower [11,12] and so in this case, the average strength will be larger than the experimental threshold, meaning that a greater proportion of the strength distribution will be accessible. If it is found that the decay in ^{194}Pb has not reached the chaotic limit, we might be able to answer a question recently addressed by Sven Åberg and collaborators [13]: Is the sudden decay from SD states an example of chaos assisted tunneling ? More generally, one could imagine a systematic search for primary γ-rays and by comparing different nuclei with different decay-out energies, attempt to locate the energy region where the onset of chaos occurs.

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