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STATISTICAL METHODS OF SPIN ASSIGNMENT IN COMPOUND NUCLEAR REACTIONS

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ABSTRACT

Spin assignment to nuclear levels can be obtained from standard in-beam gamma-ray spectroscopy techniques and in the case of compound nuclear reactions can be complemented by statistical methods. These are based on a correlation pattern between level spin and gamma-ray intensities feeding low-lying levels. Three types of intensity and level spin correlations are found suitable for spin assignment: shapes of the excitation functions, ratio of intensity at two beam energies or populated in two different reactions, and feeding distributions. Various empirical attempts are examined and the range of applicability of these methods as well as the limitations associated with them are given.

INTRODUCTION

Spin assignments to the low-lying levels in medium and heavy nuclei are generally based on indirect techniques sensitive to transition multipolarities and the relative spin difference between nuclear levels. For example, measurements of angular distributions and correlations, γ-ray linear polarization and electron internal conversion coefficients, independently or in any combination, seldom provide an unique spin assignment. In the domain of compound nuclear reactions, statistical methods can complement these standard in-beam γ-ray spectroscopy techniques and increase the potential for reliable spin assignments.

So far no systematic effort has been made to explore the broad application of the statistical methods of spin assignment or to provide a "common code of practice". These methods have been applied to numerous specific cases and were empirical in character, occasionally supported by systematic tests of the method or detailed model calculations. Furthermore, these methods are not uniformly accepted throughout the research community. A short review of these methods may clarify some of the problems listed above.

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The statistical methods are based on: a) the ability to detect the change in the intensity feeding low-lying levels of interest due to changes in the average spin of the formation states (the latter caused by modification of the reaction process), and b) the statistical process governing the decay of the formation states to the states of interest. After an extensive literature search, three basic correlation patterns of level-spin and γ-ray intensities feeding these levels were found to be reliable spin indicators.

EXCITATION FUNCTIONS

The shape of the excitation functions has two features, which are directly spin dependent. The first such feature is that the excitation function characteristic of a higher spin reaches a maximum at a higher beam energy. This correlation can be expressed quantitatively in a functional form. The second feature is that, when normalized to a weighted average of a group of curves of a given spin, the excitation functions of higher spin show higher slope. Although this relation is a qualitative one, the information contained in it can be transformed into a quantitative functional dependence using the ratio of intensities method.

The excitation function can be given for the following quantities associated with the level: "total feeding intensity" usually measured by summing over all observed processes deexciting a level, and "side-feeding intensity" measured by subtracting from the total feeding intensity the intensity due to all observed discrete transitions populating this level from above. Although the side-feeding is considered to be the closest approximation to the statistical feeding, the total feeding may also represent an adequate approximation if a level is fed by several discrete transitions and if none of them carries a significant amount of the total intensity.

In (n,n'γ) studies the γ-ray excitation functions of the level of unknown spin are compared to the empirically determined standards[1]. In (p,nγ) reactions the shape of the function is compared to the predictions derived from simple Hauser-Feshbach calculations[2]. In deuteron, alpha and heavy-ion induced reactions the slope of these functions is used in a qualitative way and is usually combined with angular distribution results to provide spin assignments[3,4]. Furthermore, the maxima of these functions can be used in a quantitative way as spin indicators[5] (see Fig. 1a).

RATIO OF INTENSITIES

The ratio of level intensity obtained at higher beam energy to that at the lower one shows a smooth functional dependence, which is characterized by a higher ratio for higher spin value. A similar function can be constructed using level intensities populated in two different reactions and leading to the same nucleus of interest. Individual γ rays deexciting the same level must have identical intensity ratios which can be used to test the

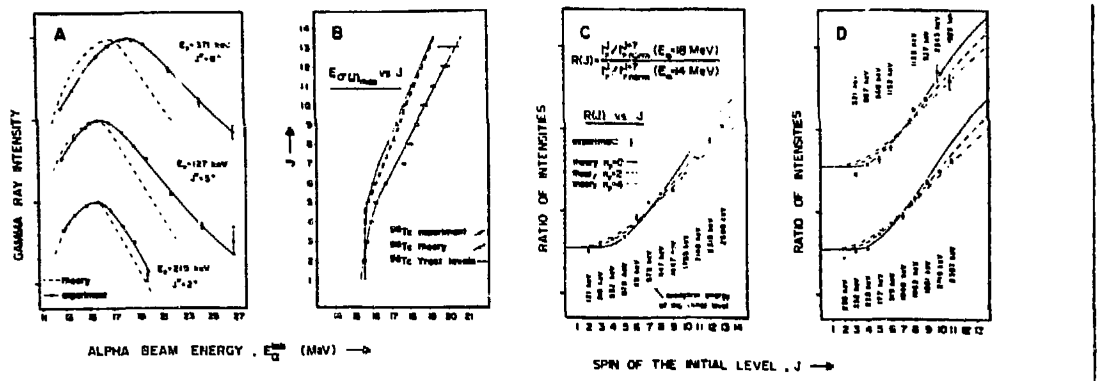

Fig. 1. A) A comparison of the experimental and theoretical excitation functions for states in ^{96}Tc populated via (α,nγ) reaction (from Ref. 5), B) The dependence of the position of the maximum in the excitation function on the spin of the initial state. C) and D) Ratios of photon intensity measured at an α energy of 18 MeV to the one at 14 MeV plotted against the spin value of the state in which the transition originated.

validity of the decay scheme or to extract the individual intensities of an unresolved doublet.

The ratio of intensity method has been researched carefully and is used in (n,γ) resonance capture reactions to study the spins of the initial as well as final levels[6]. In reactions induced by p, d, α and Li the ratio of intensities provide quantitative information on the spin of the level[3,5,7] (see also Fig. 1B, C, D), while in the heavy-ion induced reactions it is used only in a qualitative way.

FEEDING DISTRIBUTION

A fast decrease of the side-feeding intensity with increasing excitation energy is observed for levels of the same spin. It can be represented by a smooth function, which in general is separate for each spin and distinct up to some fixed excitation energy. The same data can be used in a different way; one can plot level side-feeding against level spin for a sequence of states. Although this representation may provide support for the spin assignment already made, its spin predictive power is limited.

One should note that the feeding distribution provides spin information independent of the information already enclosed in the excitation functions and intensity ratios. The first one is derived from absolute cross sections under particular experimental conditions, while the other two give a relative change in feeding intensity caused by modification of the experimental conditions.

This method is used extensively in reactions induced by light ions, frequently in conjunction with simple Hauser-Feshbach calculations[8,9]. As a method, it is particularly sensitive to the interference of nuclear structure effects in the statistical decay process[10]. In the domain of α-induced reactions, this method is less powerful than excitation functions or the ratio of intensities[3]. In heavy-ion reactions the pattern of side-feeding is used to study the decay process and the reaction mechanism itself.

LIMITATIONS OF THE METHODS

These methods are limited to levels populated in compound nuclear reactions through statistical decay processes. Consequently, one may exclude yrast levels, first few excited states or those predominantly fed by one or two transitions (due to nuclear structure selection rules). Meaningful corrections can be applied in cases when contribution from nonstatistical feeding can be clearly identified and extracted. It is recommended to use empirically determined functions for quantitative analysis.

Statistical models based on the Hauser-Feshbach formalism provide an accurate picture even in the case of complex reactions[3,5,11]. One can use simple models to predict the range of spins populated and choose optimum conditions for the experiment.

Recently an innovative method of spin assignment has been proposed for (p,γ) capture reactions[12]. It is beyond the scope of a short paper to discuss this rather elaborate technique, which has opened new opportunities for statistical methods.

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