DELAYED-PROTON AND -ALPHA EMISSION

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Abstract

Delayed-proton and delayed-alpha spectra and their branching ratios are theoretically studied for neutron deficient heavy nuclei. The results exhibit a strong model dependence of the analysis. This implies a difficulty of deducing details of the &-strength function of the precursors from such an analysis.

Introduction

The theoretical description of &-delayed particle decay in terms of a statistical model is wellknown, incorporating two main aspects: some specific assumption about the beta strength function and a statistical treatment of the competitions between particle and gamma-ray emissions.

In this work a model for the delayed proton and alpha emission from the processes 114,116Cs, 114,116Xe + (113,115I + p), (110,112Te + a) is examined. Previously, these cases have been studied experimentally[1]. Discussing their results, these authors introduced a modified structure of the &-strength function, a sharp Gaussian distribution added to a constant part, in an attempt to explain the experimental information. As it is extremely interesting to know the actual contribution of gamma resonances in the beta strength function, the above mentioned cases are examined in a modified analysis.

Methods

A description of the decay process may be formulated on the basis of the compound nucleus model. The specific approach followed here is that of ref. 2. The initial nucleus 114,116Cs, assumed to have spin-parity $\pi^+$, beta-decays with an electron capture energy $Q_{EC}$ to levels in the intermediate nucleus, which decays by the competing processes of $\gamma$, proton- and alpha emission to the final levels.

The beta decay intensity is calculated from different models, namely from the gross theory of &-decay[3] and from the approach of constant beta strength function above a threshold energy of 2.7 MeV[4].

The transmission coefficients, which describe the proton emission from the compound nucleus, are calculated from an optical model. In this work two sets of optical potential parameters are used, the set of Becchetti and Greenlees[5] which resulted from a systematic analysis of elastic scattering data mostly a high energies, and that of Johnson and Ker nell[6], gained from the study of reaction data for Sn isotopes at energies between 3 MeV and 5.5 MeV.

Concerning the &-transmission coefficients we apply the technique of Rasmussen[7]. The description of the competing $\gamma$-decays of the compound nucleus is based on the inclusion of $E1$-giant resonance transitions and $M1$-transitions. The parameters of the strength and the energy dependence of the corresponding $\gamma$-transmission coefficients are taken from ref. 8, 9.

In the calculations the electron capture energy $Q_{EC}$ and the binding energies of the proton and the alpha particle, $B_p$ and $B_a$, have to be known. The experimental information on these values is not available, but the differences ($Q_{EC} - B_p$) have been determined experimentally in the cases studied here[1,10]. These values, together with the calculated $Q_{EC}$ (112Cs), $B_p$ (113I + p) and $B_a$ (110,112Te + a) (from the table of Groote et al[11]) fix the mass parameters of the calculations.

The nuclear level densities are calculated from a procedure based on single particle spectra[12]. In this model both bound single particle states from a nuclear potential and the continuum single particle state density are taken into account. The adopted single particle potential consists of a Woods-Saxon potential, the parameters of which are taken from a droplet-model study[13].

Results

In fig. 1 a comparison between the experimental and the calculated particle spectra is shown. The calculation is based upon the gross theory of beta decay, the proton optical potential of ref. 6 and the $\eta$-transmission coefficients, mass parameters and level densities as mentioned above. The proton spectra are reproduced reasonably well, though there is a shift of the maximum of the distribution to both lower and higher energies, whereas in the case of the alpha particle spectra a systematic shift of the theoretical distributions to lower energies is seen. The calculated spectra are qualitatively similar, if a constant $\eta$-strength function is used.

The choice of the proton optical potential turns out to be of substantial significance. While the proton spectrum in the 114Cs-case is shifted to lower energies for about 0.5 MeV using the parameter set of Becchetti-Greenlees, the result shown in fig. 1 is achieved with the set of Johnson and Ker nell.

The calculated branching ratios for all protons $P_{dp}$ or all alphas $P_{da}$ provide a much less satisfactory interpretation of the experimental values, though the ratios of $P_{dp}$ and $P_{da}$ are of the order of the measured one (see table 1). The calculations exhibit a rather strong influence of changes in the mass parameters $B_p$, $B_a$, $Q_{EC}$ upon the branching ratios.

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Table 1
Experimental and theoretical branching ratios for $\beta$-delayed particles.

<table>
<thead>
<tr>
<th></th>
<th>$P_{dp}$</th>
<th>$P_{dp}:P_{da}$</th>
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<tbody>
<tr>
<td>$^{114}$Cs, exp. ((7\pm2)\times10^{-2})</td>
<td>44±3</td>
<td></td>
</tr>
<tr>
<td>$^{114}$Cs, theor. (0.50\times10^{-2})</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>$^{116}$Cs, exp. ((2.7\pm0.4)\times10^{-3})</td>
<td>75±5</td>
<td></td>
</tr>
<tr>
<td>$^{116}$Cs, theor. (0.34\times10^{-3})</td>
<td>65</td>
<td></td>
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</table>

Summary

A description of the decay of $^{114,116}$Cs in terms of a statistical model is studied. Within the framework of the gross theory of $\beta$-decay, a well-founded choice of the proton optical potential, the $\gamma$-transmission coefficients, the nuclear level densities and the mass parameters $\varphi_p$, $B_p$ and $B_\alpha$ serves to predict proton spectra, which are quite similar to the measured ones. The analysis turns out to be quite model dependent, as modifications, e.g. of the proton and $\gamma$-transmission coefficients, show. More theoretical efforts have to be started to improve the calculation of the $\alpha$-transmission coefficients, and to study the discrepancy in the absolute branching ratios between the predictions and the experimental values. In parallel to such improvements, one might be able to study possible pygmy resonances of the $\beta$-strength functions as the traces of strong single-particle transitions, expected within the shell model\cite{14}. It is to be added, that several attempts to incorporate shell effects into the gross theory of $\beta$-decay have been made\cite{15}.

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References

3. K.Takahashi,M.Yamada,T.Kondoh; Atomic Data Nucl. Data Tab. 12 (1973) 101 and references therein
5. F.D.Becchetti,G.W.Greenlees; Phys.Rev. 182 (1969) 1190
7. J.O.Rasmussen; Phys.Rev. 113 (1959) 1593

Fig. 1 Comparison of the theoretical spectra of $\beta$-delayed protons and alpha particles (full lines) with the experimental data from ref. 1,16. Details are given in the text.