CONF- 840906 - - 8

LOCATION OF A DOORWAY STATE USING THE CHANNEL n + ^{207}Pb

CONF-840906--8

DE85 001668

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ABSTRACT

The location of a doorway state in the n + ^{207}Pb channel is established through a statistical analysis of the observed partial widths for gamma-rays and neutrons. Several statistical tests developed to help locate doorway states are presented. The statistical analysis focuses on the strong correlation between large partial widths in the two exit channels. Widths in both exit channels exhibit extremely large values in the energy region near E_n = 120 keV. This clustering of large widths, even when considered seperately for each exit channel, is relatively unlikely to occur in a statistical sample. The strong correlation between channels decreases the likelyhood for this clustering of large widths to occur in a statistical sample to less than 0.0003.

INTRODUCTION

The concept of doorway states, though theoretically well founded, has been difficult to verify experimentally except in special cases, such as with analog states and fission doorway states[1]. One possible candidate for a doorway state is an apparent 1^+ doorway state, common to both neutrons and ground state photons in n+^{207}Pb p-wave data at 120 keV[2,3]. This apparent doorway state is characterized by a clustering of large widths for levels near 120 keV in both exit channels. This paper compares the gamma-ray and neutron partial widths with statistical model predictions. To make such a comparison it is neccesary to use statistical test that precisely address the question of how likely are the large observed widths and correlations. The statistical tests and their results are discussed in detail.

DISCUSSION

Figure 1 shows the accumulated widths for the neutron and gamma exit channels. A qualitative indication of the degree of correlation between widths in the two exit channels can be obtained from this figure. The shaded areas in the figure show where the sum of the widths jumps markedly in both exit channels. Such

* Work supported in part by the National Science Foundation and The Florida State University.

† Work supported by the U.S. Department of Energy under Contract No. DE-AC05-84OR21400 with the Martin Marietta Energy Systems, Inc.

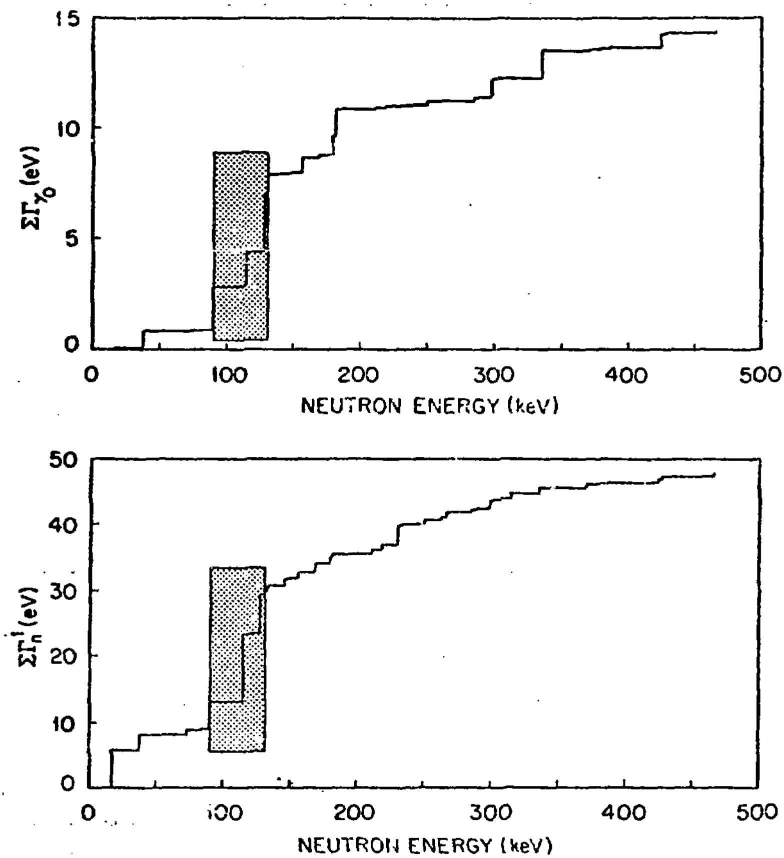

Figure 1. Cummulative sums of neutron and gamma-ray partial widths.

qualitative indications of correlations, though a good starting point are not necessarily convincing demonstrations of a doorway state's existence.

The statistical model as used to explain fluctuations[4] requires that resonance partial widths for different compound nucleus states should be uncorrelated. The actual distribution of widths will vary according to the type of exit channel. The statistical model also predicts that partial widths for different exit channels should be uncorrelated. However, when a common doorway state is present then the resonance widths for different levels in the doorway and different exit channels should be correlated and the widths may be larger than those expected from a statistical distribution of widths. There are many statistical tests that can be used to search for narrow energy regions where strong correlations exist within or between exit channels.

The correlation coefficient defined below is commonly used in

$$\rho = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{\Gamma ni - \bar{\Gamma}_n}{\sigma n} \right) \left(\frac{\Gamma \gamma i - \bar{\Gamma}_\gamma}{\sigma \gamma} \right) \qquad (1)$$

statistical tests. In eq. 1 Γ_{ni} and $\Gamma_{\gamma i}$ are the neutron and gamma widths for the ith level in the compound nucleus, $\bar{\Gamma}$ and σ are the average widths and the variances and N is the number of widths. The value of ρ obtained using the data of ref. 2 and 3 is 0.64 (between 0.35 and 0.83 at the 95% confidence level). Thus there is a correlation between the gamma-ray and neutron widths. The value of ρ obtained after removing the four largest widths in the region of the suspected doorway state is $\rho = 0.13$ (−0.27 to 0.5 at the 95% confidence level). Thus the strong correlation is due to levels near $E_n = 120$ keV.

A statistical test that is useful for locating large widths within a single exit channel is based on the expected value for the sum of N randomly selected widths. If the distribution of widths is known it can be used in a Monte-Carlo calculation to predict the sum of N randomly selected widths. In the present case the probability distribution of the Γ_γ values is well reproduced by the predicted distribution[4] given by eq. 2 with $\Gamma = 0.109$ eV.

$$P(\Gamma)d\Gamma = \frac{1}{\sqrt{\pi}} \left(\frac{\Gamma}{2\bar{\Gamma}}\right)^{-1/2} e^{-(\Gamma/2\bar{\Gamma})} \frac{d\Gamma}{2\bar{\Gamma}} \qquad (2)$$

The incomplete gamma function above $\Gamma(1/2,\bar{\Gamma})$ can be used to predict the distribution of the sum of N widths, which should have a distribution of the form $\Gamma(N/2,\Gamma)$[5]. Using these distributions and the tables of ref. 6 we find that the probability of four Γ_γ values adding to 7.1, as do those near $E_n = 120$ keV, is 0.0005. The Γ_n distribution is not well fit by the predicted incomplete gamma distribution. Consequently a Monte-Carlo approach using the observed width distributions was adopted to try to predict the distribution of the sum of the four Γ_n values. The Monte-Carlo calculation showed that the probability of getting a sum of 21.4, which was obtained for the four widths near $E_n = 120$ keV, is 0.0009. This result is clearly at odds with statistical predi-tions.

The distribtuion of runs tests developed by Mood[7] are well suited for locating doorway states. In this test one counts the number or runs, i.e. groups of consecutive widths above or below the average. The probability of observing N1 runs whose members are all above the average and N2 whose members are all below the average when there are A (B) widths above (below) the average width is given by eq. 3.

$$P(N1, N2) = \frac{\binom{A-1}{N1-1}\binom{B-1}{N2-1} F(N1, N2)}{\binom{A+B}{A}} \qquad (3)$$

where $\binom{A}{B}$ denotes the standard binomial coefficient and $F(N1,N2)$ is 2, 1 and 0 for $N1=N2$, $|N1-N2|=1$ and $|N1-N2|>1$, respectively.

In the measured partial widths the number of runs in both exit channels is lower than expected because the large widths are clustered. The probabilities for the observed run distributions are 0.019, 0.25 and 0.032 in the neutron, gamma-ray and combined width distributions. The later distribution was obtained by counting as above only those resonances for which both the neutron and gamma-ray widths were above average. What is even less likely is the length of the runs in these three distributions. The probability distribution for the length of runs is given by eq. 4.

$$P(N_{ij}) = \frac{\begin{bmatrix} N1 \\ N1i \end{bmatrix} \begin{bmatrix} N2 \\ N2j \end{bmatrix} F(N1, N2)}{\begin{bmatrix} A+B \\ A \end{bmatrix}} \qquad (4)$$

where the square brakets denote the standard multinomial coefficient. In the above equation N1i is the number of runs whose i members are all above the average width and N2j is the number of runs whose j members are all below the average. Summing N1i (N2j) over all i (j) values gives N1 (N2). The probabilities of observing the runs distributions seen in the data of ref. 2 and 3 is 0.00019, 0.00041 and 0.00029 for the neutron, gamma-ray and combined widths, respectively.

CONCLUSION

The clustering of large widths correlated in the neutron and gamma exit channels which is observed in the n + ^{207}Pb reaction is clearly non-statistical. Of the three tests used the distributions of runs test seems to be the most sensitive to the presence of large, correlated widths. The other two tests worked well in this case but do not test for all of the characteristics of doorway states and thus may be less sensitive to their presence than the runs tests.

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