SHORT NOTE

Statistical Construction of Resonance Structure in the Unresolved Resonance Region, (II)

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A practical new method for the statistical construction of resonance structures in the unresolved resonance energy region is reported. It has been already mentioned in a previous note (1) under the designation of “revised method”.

For consistency with low-resolution experimental cross section data, we require again that the resonance structure to be generated should reproduce the evaluated values of fine-group average cross sections \( <\sigma_v>g \) on all of the fine groups in the whole energy range of interest. By fine groups we mean energy intervals of 0.05–1 keV width, with the unresolved resonance region of interest (about 10 keV wide) divided into several dozen such intervals. The widths of the fine groups are determined arbitrarily to suit the experimentally observed energy structure of cross sections. (The intervals do not require to be uniform, either in energy or in lethargy.)

Suitable arrangement of the generated resonance parameters should permit us to obtain a resonance structure meeting the above requirement within predetermined error. In the present method, we make use of the evaluated “fine-group average resonance parameters” \( <\Gamma^r_v>_p <\Gamma^f_v>_p \) etc. as an auxiliary tool to determine the desirable arrangement of the resonance parameters. These fine-group average resonance parameters are evaluated(2) by the conventional method so as to be consistent with the evaluated fine-group average cross sections. For correct application of the statistics of resonance parameters, random samplings of resonance parameters from the statistical distribution functions are made not on each of the fine groups but on the broad energy ranges. Each broad energy range should contain at least several hundred resonances for each \( (l,f) \)-sequence in order to maintain correct statistics for the resonance parameters. The whole energy range of interest consists of a few broad energy ranges, and each broad energy range consists of between several and say fifteen fine groups.

The main procedure of the present method is described briefly. The steps to determine any \( (l,f) \)-sequence of resonances in a broad energy range are as follows:

1. To generate a set of \( N \) random numbers \( \{D_i\} \) corresponding to level spacings, and to determine the number of resonance levels \( N_i \) in each fine group \( g \) contained in the broad energy range \( (E_i, E) \), where \( i = 1, 2, \ldots, N, E_i = E_{i-1} + D_i, E \geq E_i \), and \( \sum N_i = N \) (total number of resonance levels in the broad energy range).

2. To generate a set of \( N \) random numbers \( \{X_i\} \) for each type of resonance width \( X \) using the average resonance parameter \( <X>_g \) for the broad energy range, where \( i = 1, 2, \ldots, N \), and the letter \( X \) stands for \( \sigma_v, \Gamma^r_v \) and \( \Gamma^f_v \).

3. To distribute \( X_i \)'s among all fine groups in the broad energy range without duplication in such manner as to ensure that the number of \( X_i \)'s allotted to the \( g \)-th group is \( N_i \) and that the average value of them is close to the \( g \)-th fine-group average resonance parameter \( <X>_g \). To realize such a distribution, the allotment of \( X_i \)'s to each fine group is determined with the aid of a set of \( N \)“reference numbers” \( \{Y_i\} \), which is explained below. The procedure for this allotment is illustrated schematically in Fig. 1: A set of reference numbers \( \{Y_i\} \) corresponding to the resonance width \( X \) consists of \( G \) subsets \( \{\{Y_i\}_s, s = 1, 2, \ldots, G\} \), where \( G \) is the total number of fine groups in the broad energy range and \( s = 1, 2, \ldots, N_s \). The \( N_s \) elements of the \( g \)-th subset \( \{Y_s\}_g \) are determined by the relation

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\[ Y_n = \int_0^\infty P(X) dX = \frac{(2n-1)}{2N_x}, \quad n=1,2,\ldots,N_x \]

where \( P(X) \) is the normalized probability density function for the distribution of resonance parameter \( X \), and \( \int X P(X) dX = \langle X \rangle_e \).

Thus determined the reference numbers in the \( g \)-th subset \( \{Y_n\}_g \) follow fairly well the given statistical distribution even with relatively small \( N_x \). (The average value \( Y_n \) is close to \( \langle X \rangle_e \).) Then, a subset of random numbers \( \{X_n\}_g \) allotted to the \( g \)-th fine-group through the procedure in Fig. 1 is expected to result in an average value \( Y_e \) that is nearly equal to \( \langle X \rangle_g \).

Fig. 1 Procedure for determining distribution of resonance parameters

(A) All the reference numbers \( \{Y_n\}_g \) (see text) are arranged in the order of magnitude.

(B) By this arrangement, the "\( m \) to-\( n \) correspondence" is determined, which means that the \( m \)-th reference number \( Y_m \) comes to fall on the \( n \)-th position in the ascending order.

(C) Next, the random numbers \( \{X_n\}_g \) are also arranged in the order of magnitude.

(D) Finally, making use of the above "\( m \) to-\( n \) correspondence", they are re-arranged in such manner as that the \( n \)-th number \( X_n \) in the ascending order is placed in the \( m \)-th position of the final array.

**Table 1 Fine-group average resonance parameters for \(^{239}\)Pu**

<table>
<thead>
<tr>
<th>( E_L ) (keV)</th>
<th>( \langle \Gamma_{2}^{\alpha} \rangle_{g} ) (meV)</th>
<th>( \langle \Gamma_{\beta}^{\alpha} \rangle_{g} ) (meV)</th>
<th>( \langle \Gamma_{2}^{\beta} \rangle_{g} ) (meV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.035</td>
<td>0.792</td>
<td>0.281</td>
<td>19.6</td>
</tr>
<tr>
<td>1.585</td>
<td>0.880</td>
<td>0.312</td>
<td>30.9</td>
</tr>
<tr>
<td>1.234</td>
<td>0.801</td>
<td>0.359</td>
<td>45.0</td>
</tr>
<tr>
<td>0.961</td>
<td>0.749</td>
<td>0.297</td>
<td>31.0</td>
</tr>
<tr>
<td>0.749</td>
<td>0.704</td>
<td>0.250</td>
<td>18.0</td>
</tr>
<tr>
<td>0.583</td>
<td>0.745</td>
<td>0.515</td>
<td>85.8</td>
</tr>
<tr>
<td>0.454</td>
<td>0.792</td>
<td>0.281</td>
<td>64.8</td>
</tr>
<tr>
<td>0.354</td>
<td>0.942</td>
<td>0.234</td>
<td>33.6</td>
</tr>
</tbody>
</table>

The \( \langle \Gamma_{g}^{\alpha} \rangle_{s}'s \) are obtained from the group-wise evaluated values of the strength function. Other unresolved resonance data used are the same as given in the previous note(3). These data are all taken from Ref. (2). The result is illustrated in Fig. 2. The dotted lines present the \(^{239}\)Pu fission cross section and \( \alpha \)-values computed from the artificial resonance structure determined by the present method. They are compared with the evaluated experimental values (solid lines) which are the object of reproduction. (c.f. Fig. 2 with Fig. 1 of Ref. (1)). The computing time for this case was about 3 min (real time) with HITAC-5020F. The satisfactory result of this example reveals the utility of the present method.

Recently, a simple method has been proposed by Ishiguro et al. for the selection of resonance structures. Their method, how-
ever, does not appear to be adapted to the reproduction of such fine structures of cross sections in the low energy region as is treated here.

In conclusion, it may be said that a desirable resonance structure consistent with the experimentally observed cross sections can be generated easily by the present method, without sacrificing the statistical properties of resonance parameters. Using the resonance structures generated by this method, the effective cross sections and their statistical uncertainties for the unresolved resonance region can be estimated more realistically. A study along such lines is in progress.

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References


Isomeric Activation of Silver with Bremsstrahlung

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The metastable isomers of silver, namely, the 93.1 keV {superscript}107mAg (44.3 sec) and the 88.0 keV {superscript}109mAg (40 sec), can be formed directly from the ground states with bremsstrahlung or isotope photon irradiation. Because of the similar isomeric transition energies and half-lives of these two isomers, it has been difficult to identify each isomer formed simultaneously by photonuclear activation of natural silver. The photopakeks of the isomers in a γ-ray spectrum has not been resolved and the composite peak only has been observed{superscript}10–19.

Also no spectra showing two coexisting peaks of the internal conversion electrons has been recorded. Therefore, the activation cross sections have not been determined, nor could the relative yields of activation be compared. This report compares the photopakeks of {superscript}107mAg and {superscript}109mAg produced with bremsstrahlung from a 3.5 MeV electron beam and gives the values of the activation cross sections for {superscript}107Ag(γ, γ') {superscript}107mAg and {superscript}109Ag(γ, γ') {superscript}109mAg.

1. Experimental

A polyethylene vial containing 5 g of precipitated silver powder (Fisher certified reagent S-167) was encapsulated in aluminum rabbit and irradiated for 1 min with bremsstrahlung produced by the linear electron accel-

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