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SOME QUESTIONS CONCERNING THE PARAMETRIZATION OF THE CROSS-SECTIONS OF FISSIONABLE NUCLEI IN THE RESOLVED RESONANCE ENERGY REGION WITH ^{235}U, ^{239}Pu AND ^{241}Pu AS EXAMPLES

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ABSTRACT

Parametrization problems of neutron cross-sections in the resonance energy region are discussed; negative level parameters are given for ^{235}U, ^{239}Pu and ^{241}Pu.

Parametrization - the representation of a great deal of experimental data on cross-sections by a relatively small number of energy-independent parameters - is particularly important in the case of the heavy fissionable elements used in reactors. Cross-section parametrization is carried out on the basis of one of the formalisms for describing cross-sections in the resonance region, which were analysed in detail in Ref. [1].

The Breit-Wigner formalism proved to be suitable for parametrization of the ^{239}Pu nucleus, where the distance between levels is great and the interference between levels is negligible. For nuclei with appreciable interference between levels (^{235}U and ^{241}Pu) we have developed a formalism [1, 2] which, in our opinion, combines the advantages of the Breit-Wigner formalism and the Adler-Adler formalism and is free of the disadvantages of the latter. The essence of the proposed formalism is as follows: formally keeping the expression for $\sigma(E)$ in the Adlerian form we assume the parameter G_x to be a purely Breit-Wigner parameter - i.e.

$$\sigma_x(E) = \frac{A}{\sqrt{E}} \sum_{i=1}^{n} (G_{xi}\Psi_i + H_{xi}\chi_i),$$

where

$$G_{xi} = \frac{g_i \Gamma_{ni}^{\circ} \Gamma_{xi}}{\Gamma_i^2}.$$

An expression based on Breit-Wigner parameters has also been derived for H_x, but here one encounters the usual difficulty of determining the pair interference sign, so we shall not present this expression. The number of resonances taken into account, N, is defined as the minimum number necessary for the adequate regeneration of cross-sections from the parameters obtained; the region between the resonances is the most sensitive to the value of N.

The main question which arises in connection with parametrization is that of the experimental data used to obtain the parameters. From all the series of experiments for which results are available we chose those which give the fullest representation of the behaviour of cross-sections in the region under consideration and which complement one another, account being taken of sample temperature, energy resolution and cross-section normalization. The series of experimental data chosen in this way are the basis for parametrization.

To obtain a reliable system of parameters it is first necessary to solve the question of interfering and omitted levels in the experimental data. Generally, it is not difficult to get rid of the interfering resonances - it is sufficient to compare the available sets of experimental data on cross-sections among themselves and with the resonance parameter systems of the elements making up a sample. The number of omitted levels in a given energy range (i.e. resonances omitted in existing systems of parameters) is determined both by the method described in Ref. [1] and by the least squares method, on the basis of the energy dependence of the growing sum of levels. After this, the omitted resonances are arranged over an energy scale, mean parameter values are assigned to them and they are included in the parametrization procedure in the usual way.

Let us now consider the problem of negative levels. They have to be introduced because it is not possible, with any combination of positive resonance parameters, to get a good description of the energy region below 0.1 eV (especially the point E = 0.0253 eV) and above 0.5 eV, i.e. the trough between the first and second resonances; this is particularly characteristic of ^{239}Pu and ^{241}Pu, where the distances between the first and second resonances are of the order of 7 eV and 4 eV respectively. The number of negative resonances, their

position on the energy scale and their parameters were adjusted in such a way as to compensate for the difference between the experimental values of the cross-sections for the corresponding reaction and the cross-section values obtained from the parameters of the positive resonances making a contribution to the region under consideration. It was found that one negative level with E = -1.6 eV, Γ = 0.192 eV, Γ_n = 0.00246 eV, Γ_f = 0.17347 eV, Γ_γ = 0.01607 eV and J = 1 is enough for ^{239}Pu.

For ^{235}U and ^{241}Pu, it was necessary to introduce two negative levels each, with the parameters given in the table below.

Table

parameter \ nucleus	^{235}U	^{241}Pu
E_r , eV	- 0,5	- 0.25
	- 0.0I	- 0.0I
Γ , eV	0.25	0.30
	0.0I	0.0I
G_Γ , б.eV$^{1/2}$	$0.3603 \cdot I0^{-7}$	$0.69759 \cdot I0^{-4}$
	$0.464235 \cdot I0^{-4}$	$0.6650 2 \cdot I0^{-4}$
H_Γ , б.eV$^{1/2}$	$0.85I7 \cdot I0^{-4}$	$0.40549 \cdot I0^{-4}$
	0	0.0
G_f , б.eV$^{1/2}$	$-0.I022I2 \cdot I0^{-3}$	$0.0465062 \cdot I0^{-4}$
	$0.49692 \cdot I0^{-4}$	$-0.327508 \cdot I0^{-4}$
H_f , б.eV$^{1/2}$	$0.850I \cdot I0^{-4}$	$0.438284 \cdot I0^{-4}$
	0	0
G_γ , б.eV$^{1/2}$	$0.I00009 \cdot I0^{-4}$	
	$0.5 \cdot I0^{-6}$	
H_γ , б.eV$^{1/2}$	$0.I00II7 \cdot I0^{-4}$	
	0	

These parameters were not reduced to the Breit-Wigner form and not made self-consistent since the levels in question are adjustment levels and their parameters were determined at a great distance from the resonance peaks, where the main contribution is made by interference terms; one cannot therefore demand that the parameters obtained be physical parameters, and consequently it is impossible to make them self-consistent and to convert them to Breit-Wigner parameters as was done for ^{239}Pu, where we did not take interference into account. The above parameters, together with the data presented in Refs [1, 2], enable one to obtain a good description of the variations in the cross-sections in the 0.01 eV-1 eV region when the corresponding number of resonances is taken into account.

Let us now turn to the question of identifying resonances by their spins, for without this procedure it is impossible to carry out the operation of making the parameters self-consistent correctly and to determine correctly the usual Breit-Wigner parameters from the G_x values obtained in parametrization. Data on level spins for heavy fissionable nuclei are not complete as a rule and are not always reliable; in some cases, however, the situation can be rectified. Let us take each of the above-mentioned nuclei separately:

1. In ^{239}Pu the spin of the ground state is $\frac{1}{2}$, so that two values are possible ($J = 0^+$ and $J = 1^+$) for the spins of the levels of the compound nucleus; at the same time there is a very distinct difference between the total widths of resonances with $J = 0^+$ (high values) and $J = 1^+$ (low values). Consequently, on the basis of the total widths it is possible to assign spins to resonances with a fairly high degree of confidence.
2. In ^{235}U the spin of the ground state is $7/2$ - i.e. resonances with $J = 3^-$ and $J = 4^-$ are formed. At the same time, judging by the avilable data on resonance spins, there is no clear separation of widths by spin state; this is due to the relative smallness of the total widths compared with the widths in ^{239}Pu. To determine the resonance spins we used the parameters $\{G_{Ti}\}$, $\{G_{fi}\}$ and $\{G_{\gamma i}\}$

obtained as a result of parametrization of the corresponding cross-section types with the help of our formalism. One can readily see that they are linked by the relation

$$G_{Ti} = G_{fi} + G_{\gamma i} + G_{Ti}^2 \sqrt{E_{ri}}/g_i ,$$

so that it is possible to determine g_i for each resonance at which this relation is satisfied best. Although we do not claim that they are absolutely reliable, the level spins obtained in this way offer the possibility of solving the problem of self-consistency and of obtaining Breit-Wigner parameters.

3. In ^{241}Pu the spin of the ground state is $5/2$ - i.e. we have resonances with $J = 2^+$ and $J = 3^+$. However, there are no experimental data on $\sigma_\gamma(E)$ and $\sigma_n(E)$, so that it is impossible to determine the level spins as was done for ^{235}U. In determining the resonance spins, the absolute majority of which is unknown, we started with the level density ratio as a function of J, assigning a spin of 2^+ to resonances with a larger total width. Here, as for ^{235}U, there is no clear separation of total widths by spin. We consider the assigned spin values to be tentative and in need of more precise determination.

Let us now consider the procedure for making parameters self-consistent, which is closely linked with the spin questions discussed above. In this case also we can obtain self-consistent sets of parameters only if there are three cross-section types. As in the preceding case, we use the relation

$$G_{Ti} = G_{fi} + G_{\gamma i} + G_{Ti}^2 \sqrt{E_{ri}}/g_i ;$$

then, on the basis of our knowledge of the accuracy of the experiments relating to each cross-section type, we specify the resolved interval of variation of the parameters, and the parameters themselves vary

within this interval in such a way that this relation is satisfied exactly. The resulting self-consistent values are used both for regenerating the cross-sections and, on the basis of the relation

$$G_{x,i} = \frac{g_i \Gamma_{n,i}^{\circ} \Gamma_{x,i}}{\Gamma_i^2} ,$$

for obtaining Breit-Wigner parameters which in turn are necessary both for verification of the quality of parametrization (together with the cross-section values regenerated from the parameters) and for obtaining the mean parameter values and the strength function S^{o} value used for calculations in the unresolved resonance region.

The agreement between the values of S^{o} calculated in two different ways - from the parameters in the resolved resonance region and from the experimental total cross-section values in the unresolved resonance region - is also a good criterion for the quality of parametrization. For example, for ^{235}U these values are $1.069 \cdot 10^{-4}$ and $1.08 \cdot 10^{-4}$ respectively.

REFERENCES

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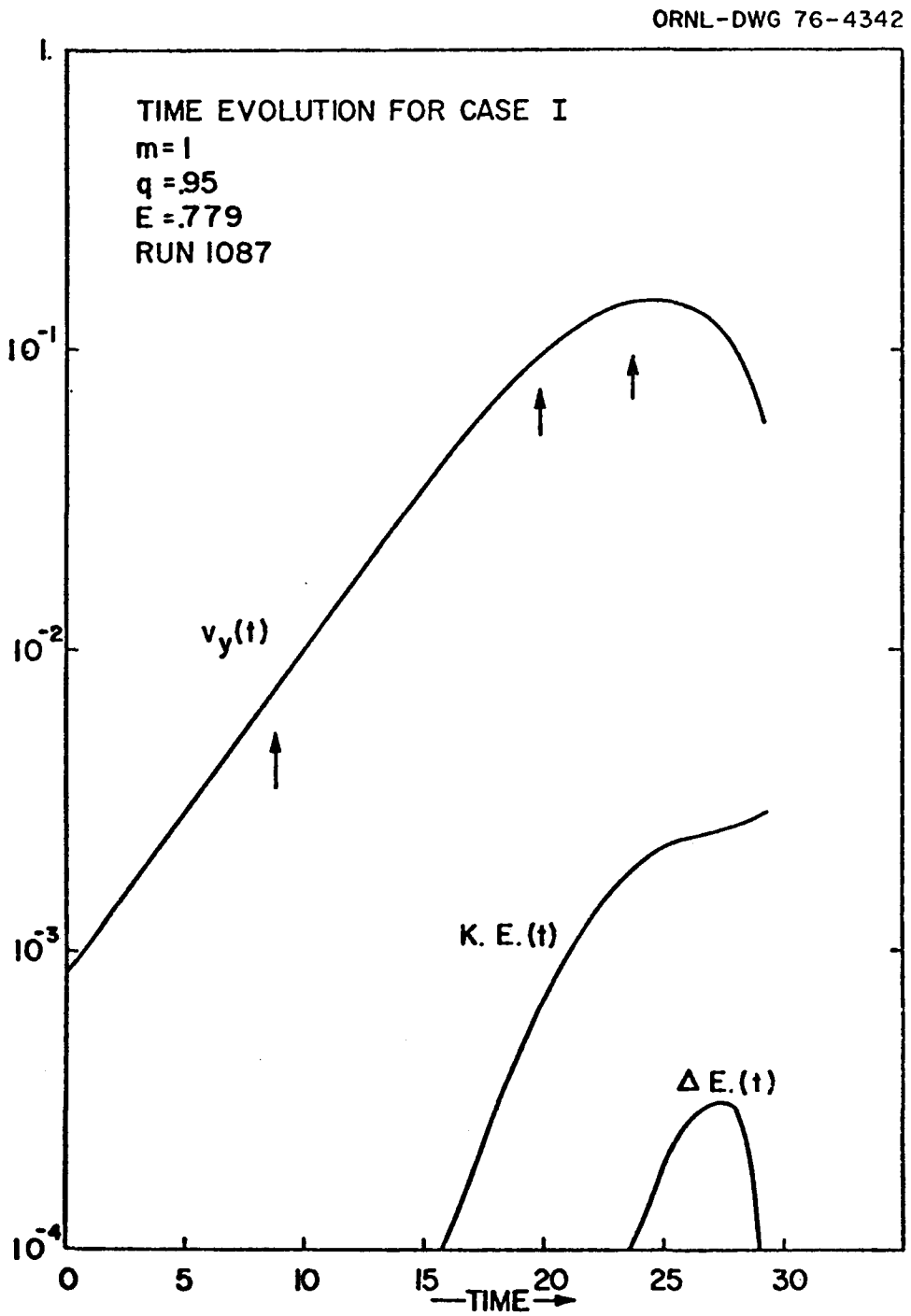
[2] ANTSIPOV, G.V., BENDERSKIJ, A.R., KON'SHIN, V.A., KORENNOJ, V.P., MOROGOVSKIJ, G.B., SUKHOVITSKIJ, E.Sh., in "Yadernye konstanty" (Nuclear constants), Issue 20, Parts 2, 3 (1975).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1.
TIME EVOLUTION FOR CASE I
m=1
q =.95
E =.779
RUN 1087
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$v_y(t)$
K. E.(t)
Δ E.(t)
0
5
10
15
20
25
30
—TIME→