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IFUSP/P-438

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Accepted for publication in the
Phys. Rev. C - Brief Report

Novembro/1983

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ABSTRACT

The strength distribution of the isoscalar Giant Quadrupole Resonance (GQR) for actinide nuclei, obtained from photon-, electron- and hadron- induced reactions, is analyzed in terms of a cranking model for the fragmentation of the GQR. The role played by the low-lying E2- strength for the correct delineation of the GQR parameters is presented.

*Supported in part by the Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq (Brazil).

KEYWORD ABSTRACT

NUCLEAR REACTIONS $^{238}U(\alpha,\alpha')$, E = 100 and 172 MeV; $^{238}U(e,f)$, E = 5-30 MeV; $^{238}U(\gamma,f)$, E = 5-7 MeV; $^{232}Th(e,f)$, E = 5-8 MeV; $^{232}Th(\gamma,f)$, E = 5-7 MeV; $\sigma(\theta)$ and $\sigma(E)$, available from the literature, are analyzed. Deduced B(E2) energy distribution for the giant quadrupole resonance. Natural targets.

PACS: $24.30.C_z$, 25.20.+y, $25.85.J_g$

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The characteristics of the isoscalar Giant Quadrupole Resonance (GQR), for actinide nuclei, have been studied intensively by means of electron-and hadron- induced reactions[1-8]. However, the question regarding the decay channels of the GQR is still open. The results available in the literature are restricted to the fission decay mode; the conclusions drawn from all these experiments are controversial with respect both to the distribution of the GQR strength (peak and width) and to its fission branching ratio.

In this brief report we would like firstly to analyze the distribution of the GQR strength in the light of the splitting of the GQR in the framework of the cranking model (as developed in ref. 9); secondly, to show that the low-energy portion of the E2-strength (near the fission barrier) represents a substantial fraction of the total GQR strength and, therefore, plays a crucial role in the determination of the GQR parameters. In order to achieve these two goals we make use of the GQR data obtained from electro- and photofission experiments for actinide nuclei. The main conclusions are compared to the results recently obtained from hadron scattering studies. The two existing coincident electrofission data[10,11), ^{238}U(e,e'f), are not considered here, because with the kinematics and procedures of these experiments it was not possible to disentangle the E2 from the E0 contributions. In addition, while the (e,e'f) spectra obtained at Stanford[11] exhibit a clear structure around 9 MeV, the similar (e,e'f) experiment carried out at Illinois[10] shows nearly structureless spectra. For the inclusive (e,f) reactions, at low energies, the E0 transitions (and all the EL transitions with L > 2) are not important (we refer the reader to refs. 8 and 12 for more details). We emphasize that it is not our intention, in this work, to discuss the present status of the GQR fission branching ratio.

The width of the GQR, e.g. ^{238}U , as deduced from the electron- and hadron-induced reactions, ranges from a maximum of ~ 7 MeV [obtained in a (^{6}Li,^{6}Li') experiment[5]] to a minimum of ~ 3 MeV [from the (α,α') experiment reported in ref. 6]; see Table 1. The main characteristics of all these available data are: (1) the centroid energy of the GQR observed in the electron-induced experiments is, systematically, ~ 2 MeV below the one observed in hadron scattering[8]; (2) the distribution of the GQR strength deduced from the hadron scattering spectra vanishes for energies below ~ 8 MeV. This second characteristic brings on a serious problem, namely: without the detection of all the E2-strength it is nearly impossible to delineate correctly both the peak and width of the GQR. The concentration of E2-strength below ~ 8 MeV, in the actinide nuclei, is not a speculation but an experimental fact, because both photofission and electrofission angular- distribution data acquired over the last twenty five years show there to be a significant E2 component at excitation energies near the fission barrier[13-18]. With the purpose of illustrating, Figs. 1 and 2 show the near- barrier E2 photofission cross sections deduced from the electrofission data[8,18] (shaded bands) for ^{232}Th and ^{238}U, respectively, and those deduced from the independent higher-resolution measurements of the photofission absolute yields and angular distributions of refs. 16 and 17; it can be seen that good agreement in overall strength has been achieved (see also Table 2). The lack of E2-strength observed in the hadron-scattering spectra, after the subtraction of the background, is somewhat alarming. In this regard it is worth remembering that such strength has to be missed in hadron work since there the backgrounds are drawn to exclude everything except the narrower structures sticking out from these backgrounds.

The physical quantity to be extracted from the electrofission data is[8] $\frac{dB}{d\omega}(E2;\omega)\frac{\Gamma_f(\omega)}{\Gamma}$, where $\frac{dB}{d\omega}(E2;\omega)$ is the GQR strength function, and $\Gamma_f(\omega)/\Gamma$ is its fission branching ratio. It is a well-known fact that the fission branching ratio for actinide nuclei, from photofission experiments, at energies above (~ 1-2 MeV) the fission barrier, is nearly constant[19]. Therefore, the shape of $\frac{dB}{d\omega}(E2;\omega)\frac{\Gamma_f(\omega)}{\Gamma}$ resembles the main trend of $\frac{dB}{d\omega}(E2;\omega)$ as a function of the excitation energy ω. Figure 3A shows the results for the GQR of ^{238}U obtained from electrofission[2,3,8] and a recent (α,α') experiment[7]. Figure 3B shows a curve representing the GQR strength function based on the theoretical prediction of Abgrall et al.[9]; we generated that curve by adding three Breit-Wigner shaped curves having energy peak and area given by theory[9] (see Fig. 4) and an width of 3 MeV each (which is reasonable for spherical heavy nuclei[20]). The total width obtained is 5 MeV, in agreement with the experimental (e,f) result (see Table 1). Our simplified calculation using the Abgrall et al. model does not necessarily mean that all the hadron results are wrong, but in the particular case of the GQR we have demonstrated above that a substantial fraction of the total

E2-strength (see Figs. 1,2 and Table 2) is not observed in the hadron scattering experiments. Regarding the theoretical predictions of ref. 9 for the splitting of the giant resonances we note that: in the (α,α') study of ref. 7 the splitting of the Giant Monopole Resonance (GMR) is well described by this theory, while the distribution of the GQR strength disagrees with this same theoretical prediction (Fig. 4); the authors of ref. 7, however, do not even appear to be surprised.

We conclude this report accentuating that, the 1/3 of the total E2-strength which is not observed in the GQR bump of the $^{238}U(\alpha,\alpha')$ spectrum[7] may well be distributed at lower excitation energies, as found in the electron- and photon- induced fission experiments. Therefore, the correct evaluation of the line shape (peak and width) depends on the correct detection of the strength distribution, and not merely on a bump sticking out from a huge background. As final remarks, we would like to point out that: (1) the findings of the hadron-induced experiments (zero E2-strength below 8 MeV, for actinide nuclei) for the GQR are physically unreasonable (as illustrated in Figs. 1 and 2); (2) it would seem that a solution to this problem needs to be found before one can go very far in the interpretation of the results, and before inferring too much on the basis of too little information; (3) electro- and photofission angular distributions have proven to be a sensitive tool for the study of E2-strength distribution, in even-even actinide nuclei, particularly those portions of the strength located at low excitation energies (near the fission barrier).

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TABLE 1

Parameters of the GQR for the ^{238}U

Reaction	Width (MeV)	Centroid (MeV)	Ref.
theory	5.0	9.0	this work
(e,f)	5 ± 1	8.3 ± 0.4	2,3,8
$(^6Li,^6Li')$	~7	~10.5	5
(α,α')	4.0 ± 0.5	~11	4
(α,α')	3.0 ± 0.4	10.8 ± 0.3	7
(α,α')	2.9 ± 0.3	11	6

TABLE 2

E2 fission strength concentrated near the fission barrier (5-7 MeV)

Nucleus	E2 strength[a)]	
^{232}Th	8 ± 2[b)]	~ 7[c)]
^{234}U	10 ± 2[d)]	16 ± 3[e)]
^{236}U	13 ± 2[d)]	8 ± 2[e)]
^{238}U	6 ± 1[d)]	7 ± 1[e)]

a) $\frac{1}{B(E2)} \int \frac{dB}{d\omega} (E2,\omega) \frac{\Gamma_f}{\Gamma} d\omega \times 100$, where B(E2) is equal to one

E2 energy-weighted sum-rule unit.

b) Ref. 18.

c) Derived from the cross sections published in Ref. 17.

d) Ref. 8.

e) Derived from the cross sections published in Ref. 16.

FIGURE CAPTIONS

FIG. 1 - Solid curve: E2 photofission cross section for ^{232}Th at low energies (Ref. 17); shaded band: E2 photofission cross section from the electrofission data of Ref. 18.

FIG. 2 - Solid curve: E2 photofission cross section for ^{238}U at low energies (Ref. 16); shaded band: E2 photofission cross section from the electrofission data of Refs. 2 and 3.

FIG. 3 - A) E2 strength function for ^{238}U as a function of the excitation energy ω, from Ref. 7 (α,α') and Refs. 2 and 3 (e,f).

B) Theoretical calculation of the E2 strength function for ^{238}U (details in the text and in Ref. 9).

FIG. 4 - Comparison of the GQR centroid energy from Ref. 7 (α,α') and Refs. 2 and 3 (e,f) with the theoretical prediction of Ref. 9.

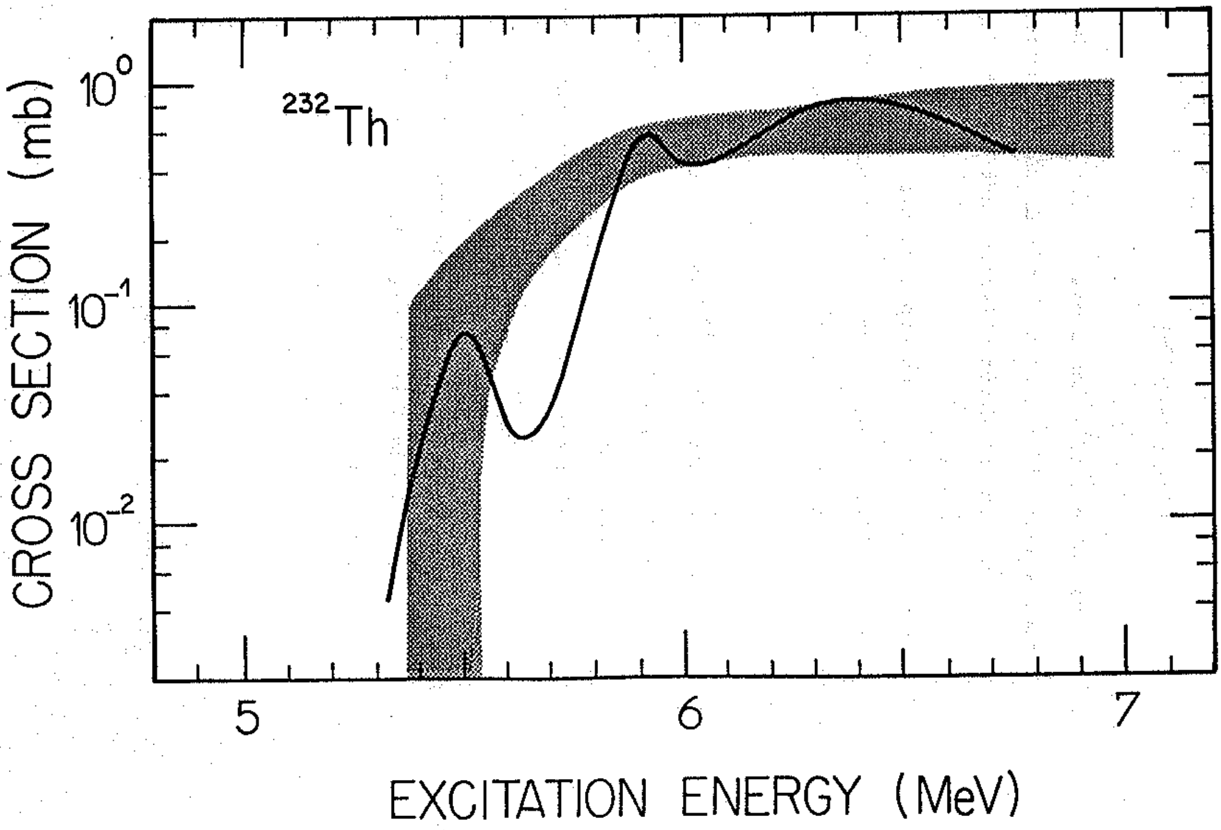
10^0
10^{-1}
10^{-2}
CROSS SECTION (mb)
^{232}Th
5
6
7
EXCITATION ENERGY (MeV)

Fig. 1

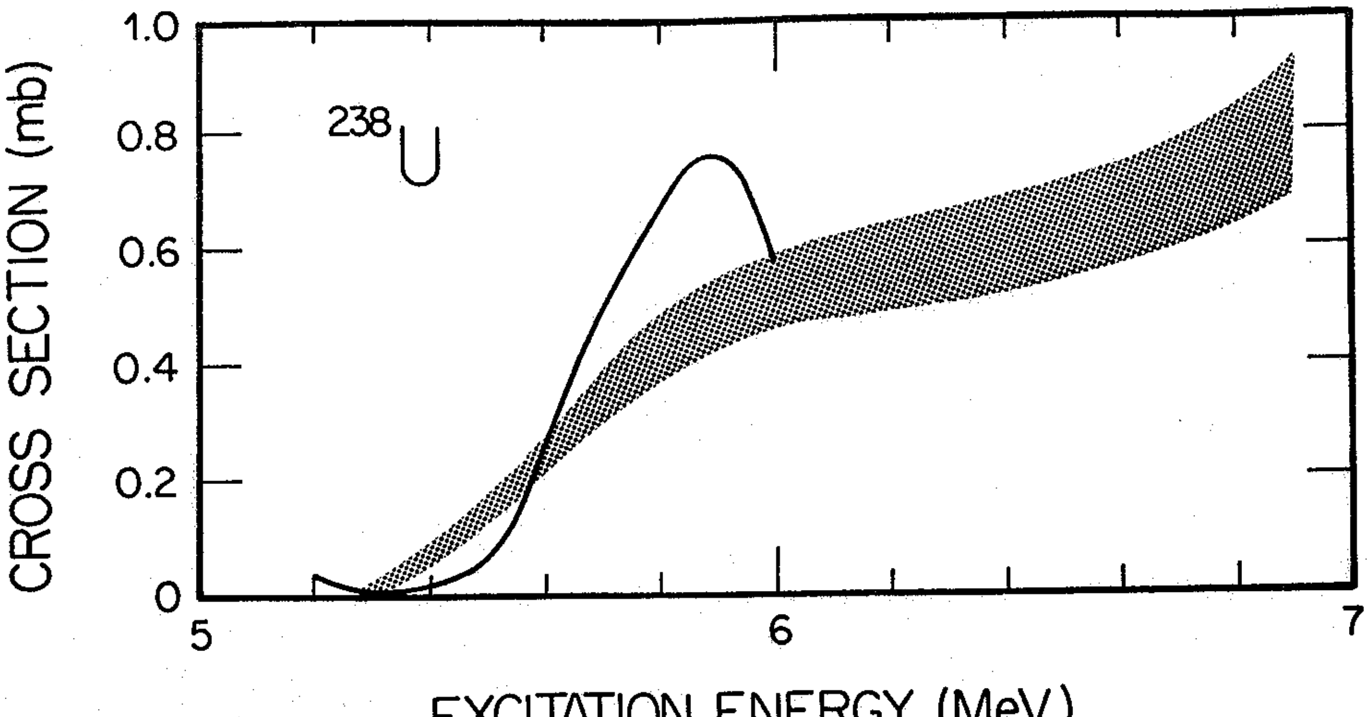
1.0
0.8
0.6
0.4
0.2
0
CROSS SECTION (mb)
^{238}U
5
6
7
EXCITATION ENERGY (MeV)

Fig. 2

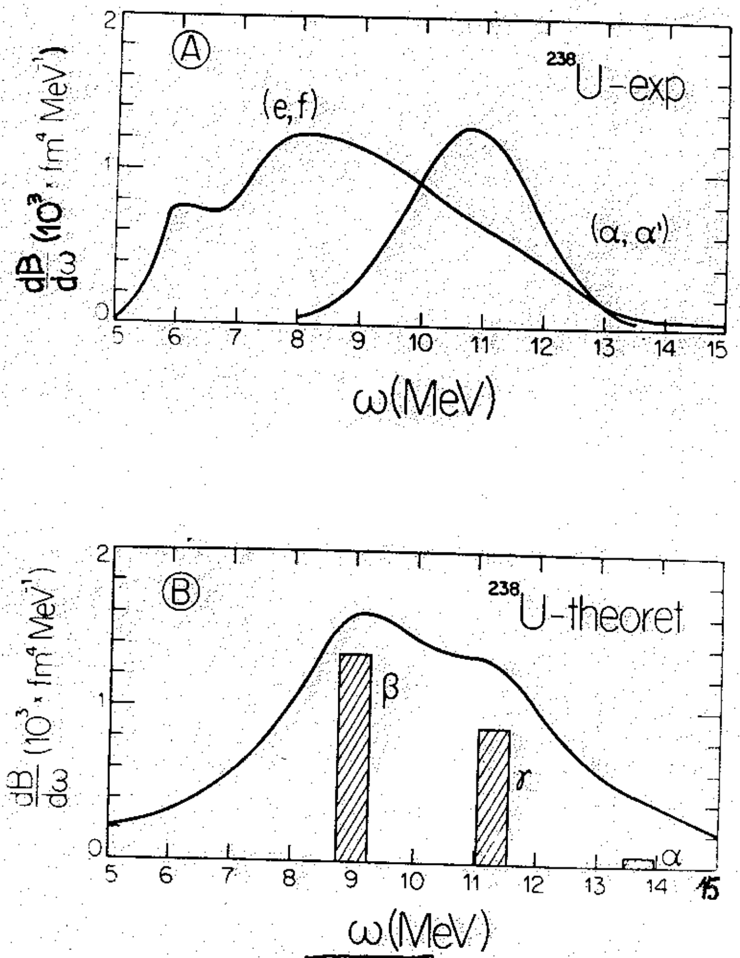
A
238U-exp
(e,f)
(α, α')
dB/dω (10³ × fm⁴ MeV⁻¹)
ω(MeV)
B
238U-theoret
β
γ
α
dB/dω (10³ × fm⁴ MeV⁻¹)
ω(MeV)

Fig. 3

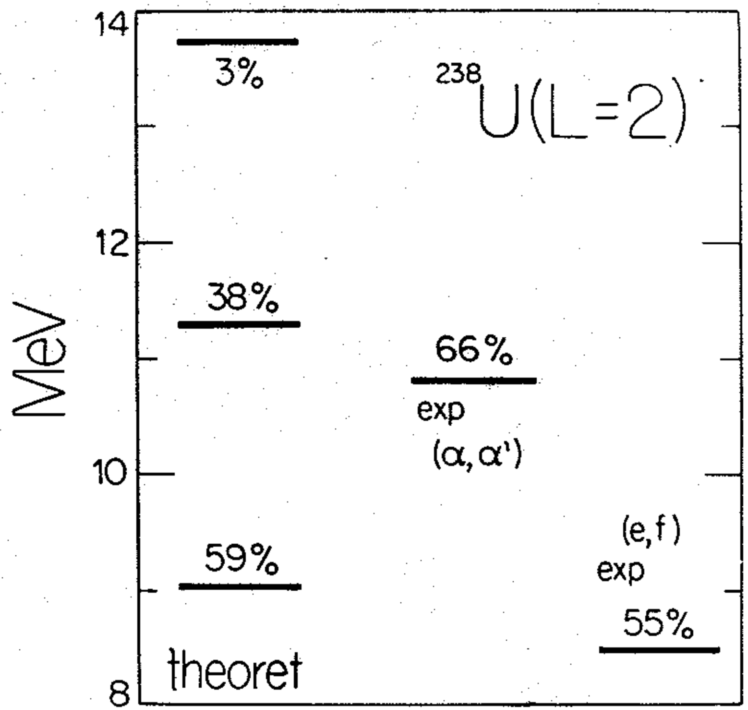
238U(L=2)
MeV
3%
38%
59%
theoret
66%
exp
(α,α')
(e,f)
exp
55%

Fig. 4