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Excitation Function and Half-life for the Fission Isomer ^{240m}Pu from the $^{238}U(\alpha,2n)^{240m}$Pu Reaction

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ABSTRACT

The excitation function for the fission isomer ^{240m}Pu produced in the reaction of ^{238}U with α particles, has been measured at laboratory incident energies ranging from 20.1 to 27.3 MeV. A value of $3.8^{+0.6}_{-0.4}$ nsec was obtained for the half-life of ^{240m}Pu. The results are compared with other measurements performed using different experimental methods. (Author)

Introduction

The ^{240m}Pu fission isomer has been studied in detail by several authors, and relative energies and spins of levels in the second potential well have been determined. For this isomer, six measurements of half-life and excitation function using different techniques were published, with half-lives ranging from 2.4 to 9 nsec /1-6/. Cross-sections also show disagreement.

In this work, new measurements are presented for the excitation function and half-life of the ^{240m}Pu fission isomer, formed in the reaction $^{238}U(\alpha,2n)^{240m}Pu$. Experiments were performed at α-particle energies of 20.1, 21.1, 21.6, 22.2, 24.2, 25.2 and 27.3 MeV (±0.1 MeV)

Experimental Procedure

Alpha-particles from the variable energy Cyclotron of the Instituto de Engenharia Nuclear, Rio de Janeiro, with energies up to 28 MeV were used. The energy spread of the beam was about 100 keV. The target consisted of metallic natural U, which was evaporated on an ordinary 4 mg/cm^2 aluminum foil. Target thicknesses ranged from 24 to 130 μg/cm^2. Due to a cooling system and good thermal contact between target and target holder, currents up to 5 μA could be used /7/.

To discriminate isomeric from prompt fission fragments, the fission in flight method was employed /8/, the geometry of which is shown in the inset of fig. 1. The α-particle beam was collimated by two 5mm tantalum slits, 200 cm apart, producing a beam spot of 5.5 mm diameter at the target.

The detector, a policarbonate foil (MAKROFOL), 100 μm thick, was placed on the inner wall of a 24.5 mm radius cylinder. Prompt fission fragments were monitored with a Si surface barrier detector, set at 60^o to the incoming beam.

For some energies, two runs were performed to measure prompt and isomeric fission distributions with an accumulated charge of about 200 μC and 20.000 μC, respectively. The short run gave the 90^o prompt fission cross-section, which in turn was used to determine the isomeric to prompt fission ratio.

After irradiations the MAKROFOL foil was etched, according to procedures described in /9/. Optical scanning with a microscope was used to measure track densities.

The distribution of tracks produced by the fission fragments on the detector foil, allows the determination of the half-life and the cross sections for isomeric and prompt fission σ_i and σ_p. The extrapolated ratios of isomeric to prompt fission track densities at 90^o, yield the cross section ratios σ_i/σ_p. Through this normalization the effect of the Coulomb barrier on the excitation function is eliminated. For thick targets the fraction of isomeric nuclei which are not able to leave the target was taken into account. Monte-Carlo simulated curves /10/ for different half-lives were compared with the experimental ones. From this comparison the half-live and the cross section σ_i were obtained. The simulations took into account corrections for the velocity distribution and angular spread of the recoil nuclei leaving the target, and for the finite target size.

An isotropic angular distribution for isomeric fission fragments was assumed, consistent with experimental results of ref. /11/. In the calculations it was assumed that the recoiling nuclei, go into a cone with a half-opening of 45° and are uniformly distributed /13/. The results obtained for the half-life differ at most by o.1 ns in comparison with calculations with no angular spread.

It was not necessary to include a minimum detectable angle of incident fragments for the following reasons: i) with optical scanning the observation cut-off for the angle of incidence is nearly 0° /6/; ii) for MAKROFOL the "critical angle of etching" is 3° /12/; iii) in the geometry used, an angle of incidence lower than or equal to 3° is highly unprobable.

Results and Discussion

In fig. 1 a typical experimental result for the track distribution of fission fragments is shown for a thick target of 130 $\mu g/cm^2$. Simulated track distributions for half-lives of 3.4, 3.8 and 4.4 ns are included (curves I, II, III). A least squares fit to the experimental distribution gives a half-life of 3.8 ns with an error of about $\left(^{+0.6}_{-0.4}\right.$ ns. (Curve IV was calculated without corrections for the velocity distribution of the recoil nuclei, and for $T_{1/2} = 3.8$ ns).

For the half-life determination thick targets were used, for which the velocity spread ranges from zero to the maximum value, given by momentum conservation. Thus no uncertainty exists for the lower limit of the velocity.

For cross-section measurements mainly thin targets were used, for which the range of the recoils was larger than the target thicknesses. This ensures that all recoiling nuclei leave the target, thus reducing the experimental error.

In table I a comparison with other half-life measurements is given. Our value of $3.8\,^{+0.6}_{-0.4}$ ns is in good agreement with the results obtained with electronic techniques /2,5/. The measurements performed with different fission in flight experimental arrangements show less agreement with ours.

Cross sections σ_i and ratios σ_i/σ_p have been measured for energies from 20.1 to 27.3 MeV. The results are shown in Table II and Figs. 2 and 3.

The excitation function (σ_i/σ_p) in Fig. 3 was compared with ref. /5/, and a discrepancy of a factor of two exists, at the most. Our results for σ_i (Fig. 2) are in good agreement with the results obtained in a different detection geometry with the recoil method /6/. Disagreement exists with experiments performed with electronic techniques /2, 5/.

We may conclude that our experiment represents a contribution for resolving the existing discrepancies in the experimental results, concerning the half-life and excitation function of the fission isomer ^{240m}Pu.

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List of Tables and Figures

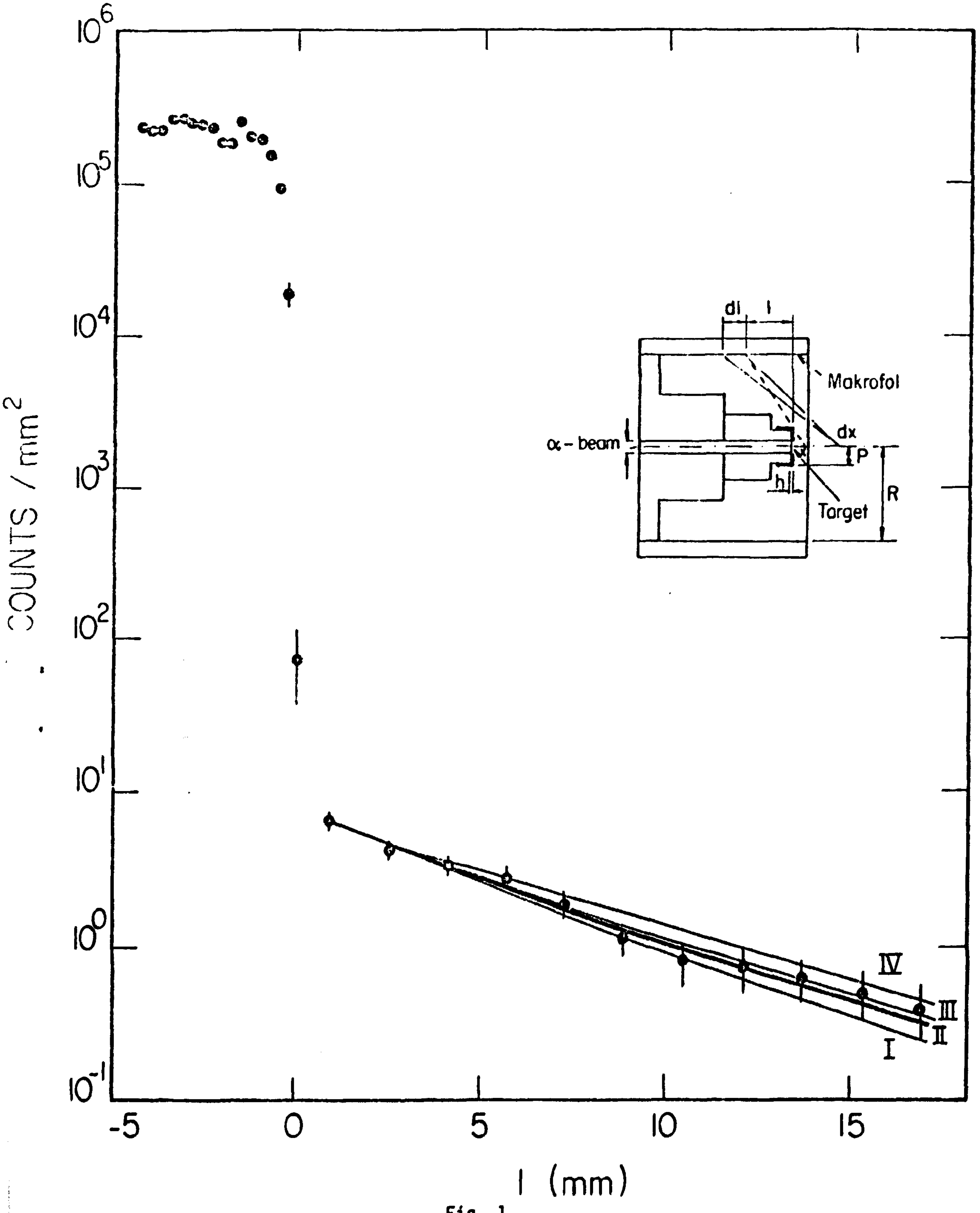
Table 1

	Ref.	Reaction	Energy(MeV)	Target thickness ($\mu g/cm^2$)	$T_{1/2}$(ns)
Electronic Techniques	2	$^{238}U(\alpha,2n)$	23 - 28	not specified	4.4 ± 0.8
	5	$^{238}U(\alpha,2n)$	21 - 28	100 - 400	3.8 ± 0.3
	4	$^{239}U(n,\gamma)$	22	1000 - 1500	$\{$4.1 a 5.2 29 ± 3.8
Fission in flight	1	$^{239}Pu(\alpha,p)$	13.0	5 - 30	9 ± 4
	3	$^{238}U\ (\alpha,2n)$	26.1	100	7 ± 2
	6	$^{238}U\ (\alpha,2n)$	20.0-37.4	>200	2.4 ± 0.5
	Present Work	$^{238}U\ (\alpha,2n)$	20.1-27.3	24 to 130	$3.8^{+0.6}_{-0.4}$

Table 2

Reaction $^{238}U\ (\alpha,2n)^{240m}Pu$

Bombarding energy(lab) (MeV)	Isomer cross section σ_i (μb)	Cross section ratio σ_i/σ_p
20.1	0.5±10%	2.5×10^{-5}±20%
21.1	1.2±10%	
21.6	4.4±20%	7.0×10^{-5}±30%
22.2	4.8±10%	6.4×10^{-5}±20%
24.2	11.5±10%	5.3×10^{-5}±20%
25.2	8.9±10%	2.8×10^{-5}±20%
27.3	4.1±20%	8.1×10^{-6}±30%



10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
COUNTS / mm²
-5
0
5
10
15
l (mm)
dl
l
Makrofol
dx
α - beam
P
R
h
Target
IV
III
II
I

Fig. 1

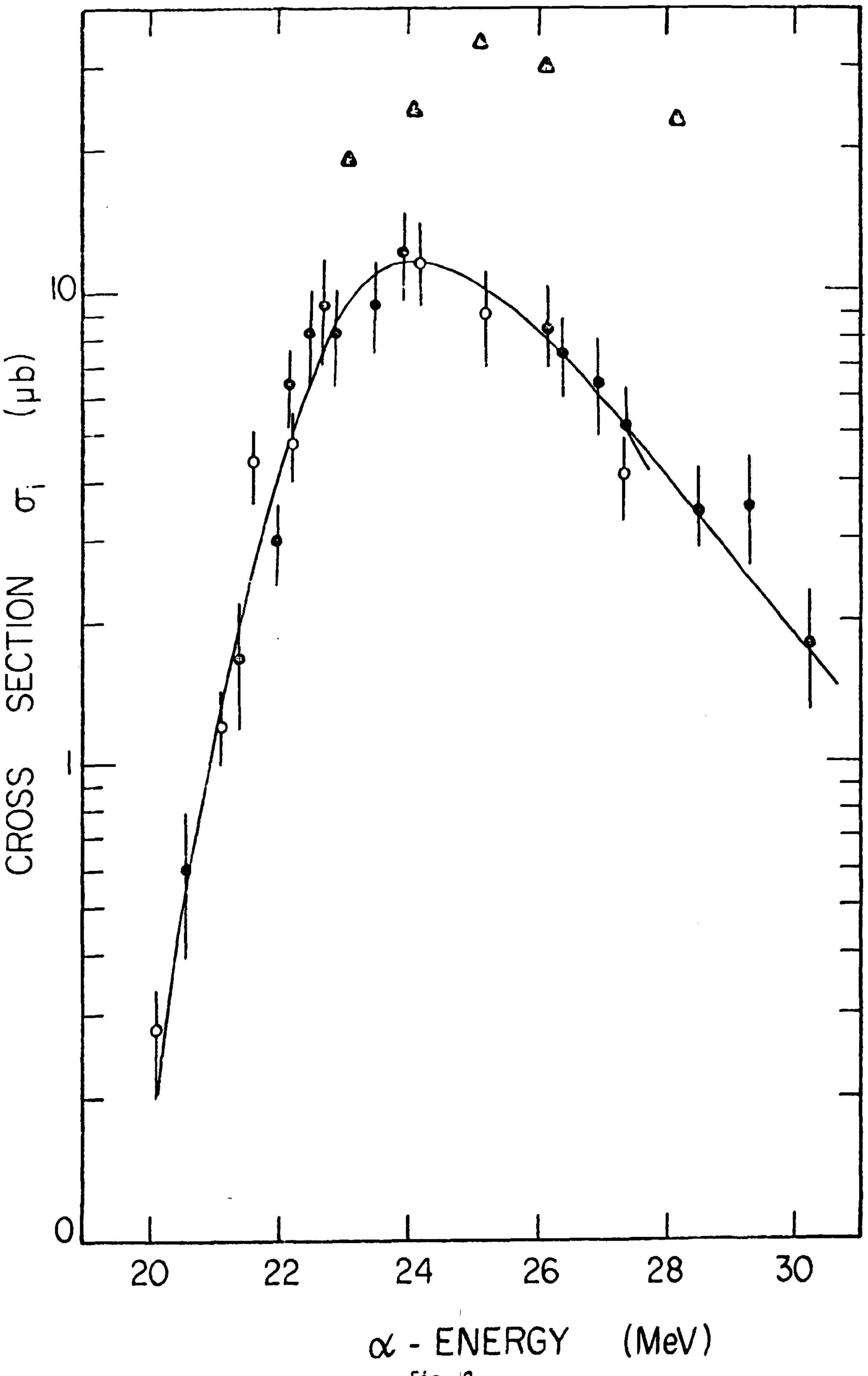


Fig. 2

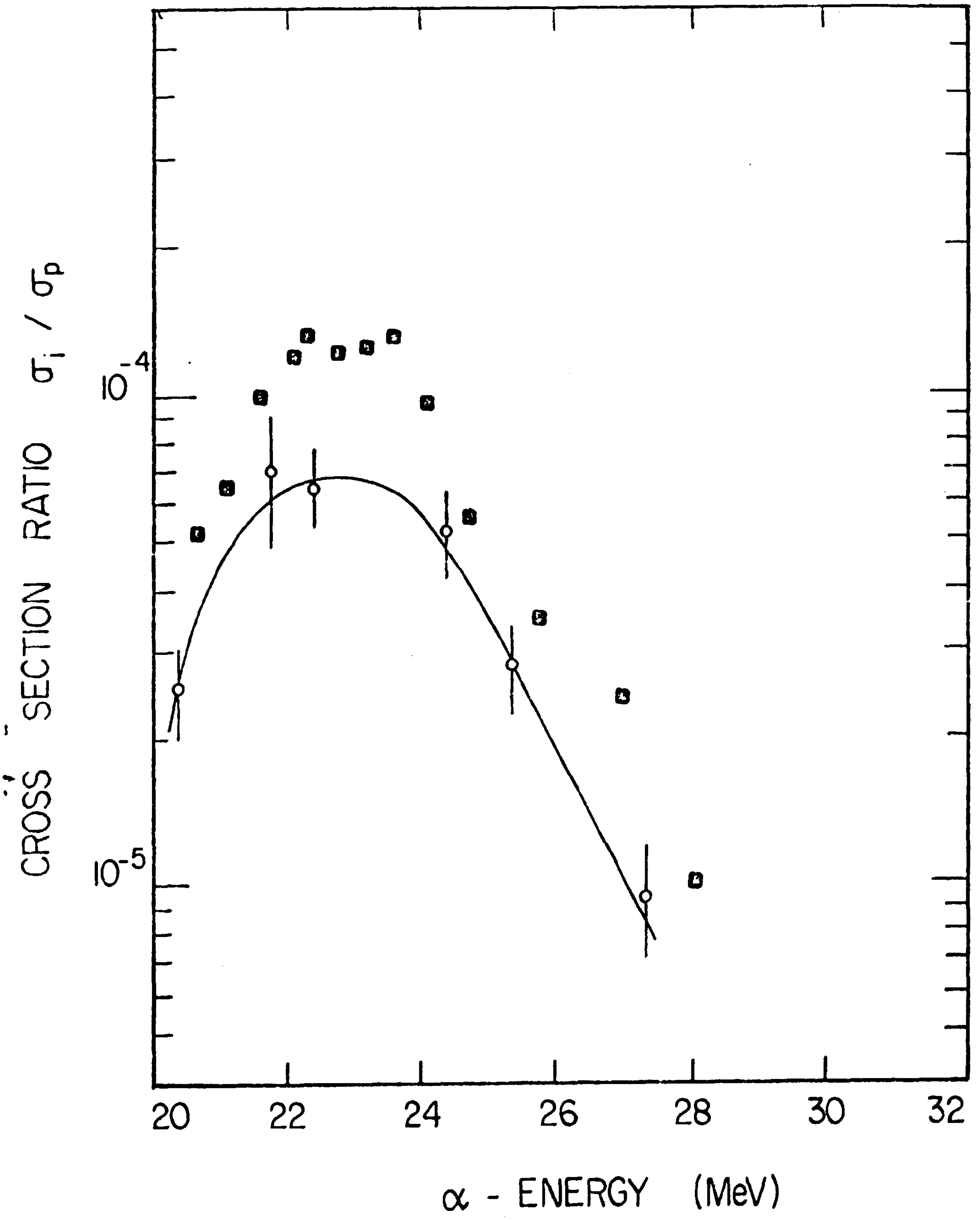

CROSS SECTION RATIO σ_i / σ_p
10^{-4}
10^{-5}
20
22
24
26
28
30
32
α - ENERGY (MeV)

Fig. 3