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MULTIPOLARITIES OF NUCLEAR TRANSITIONS INVOLVED IN THE ONE NEUTRON DISINTEGRATION OF $^{238}U^{+}$

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SUMÁRIO

São apresentados os resultados experimentais obtidos para a secção de choque $^{238}U(e,e',n)^{237}U$, na região de energia 6-25 MeV. A análise desses resultados pelo método dos fótons virtuais mostra que a emissão de neutron se processa exclusivamente por absorção E1, estabelecendo um limite superior para a intensidade de transições E2 que é de apenas 0,25 por cento das transições E1. Os dados existentes sobre os canais de decaimento da ressonância isoescalar de quadrupolo no ^{238}U são comparados com os de absorção E2 por esse núcleo. São discutidas evidências experimentais que indicam a existência de seletividade dos modos de decaimento em relação ao spin e paridade da ressonância excitada. É apresentado um teste da sensibilidade de secções de choque de eletrodesintegração quanto a existência de componentes de quadrupolo.

ABSTRACT

Measurements of the electrodisintegration cross section $^{238}U(e,e',n)^{237}U$, in the energy region 6-25 MeV are presented. A virtual photon analysis of experimental data shows that neutron emission occurs only through E1 absorption. Our data establish un upper limit to the strenght of E2 transitions, which is only 0.25 percent of the E1 transitions. Existing data on the decay channels of the isoscalar giant quadrupole resonance in ^{238}U are compared with available data on E2 absorption by this nucleus. A discussion of available experimental data, indicating a selectivity of decay modes on the spin and parity of the excited resonance is presented. The sensitivity of electrodisintegration cross sections to the existence of quadrupole components is assessed.

NUCLEAR REACTIONS $^{238}U(e,e',n)^{237}U$; E=6-25 MeV; measured $\sigma_{e,n}(E)$; DWBA virtual photon analysis, deduced photoabsorption λL.

I. INTRODUCTION

It has been shown, by the branching between (γ,n), $(\gamma,2n)$ and $(\gamma,3n)$ cross sections, that once the Photonuclear Giant Resonance(PGR) has been excited, its decay mode is predominantly statistical[1]. In heavy nuclei, in the energy region below the threshold for $2n$ disintegration, the decay is dominated by one neutron emission, as Coulomb barrier inhibits charged particle emission.

The PGR is actually composed of an Isovector Giant Dipole Resonance,(GDR) plus an Isoscalar Giant Quadrupole Resonance (GQR) and possibly other multipole modes[2]. The GQR and GDR, located at $63/A^{1/3}$ MeV and $80/A^{1/3}$MeV, respectively, are in the energy region where neutron emission is the dominant decay mode of the PGR. As there is no known selection rule which forbids a dipole or quadrupole resonance to decay by neutron emission, one would expect that the decay of both the GDR and GQR, are similarly dominated by neutron emission.

It is however difficult, due to their relative strength, to obtain the dipole and quadrupole components, from measurements of (γ,n) cross sections.

In this paper we present measurements of the absolute electrodisintegration cross section $^{238}U(e,e',n)^{237}U$. These measurements have been performed in order to study the strength of $E1$ and $E2$ contributions to this reaction.

As it is well known(3,4) the $E2$ virtual photon spectra are one order of magnitude bigger than the corresponding $E1$ spectra for high Z nuclei (see Fig.1). Consequently, measurements of the electrodisintegration cross section are a sensitive tool for the study of $E1$ and $E2$ contributions in a particular decay channel of the PGR. We discuss below the sensitivity of this method.

II. THE VIRTUAL PHOTON METHOD

The electrodisintegration cross section by emission of a particle x (integrated over all scattering angles), $\sigma_{e,x}(E_0)$ is related to the corresponding photodisintegration process, through:

$$\sigma_{e,x}(E_0)=\int_0^{E_0}\sum_{\lambda L}\sigma^{\lambda L}_{\gamma,x}(E)N^{\lambda L}(E_0,E)E^{-1}dE \qquad (1)$$

where E_0 is the electron incident energy, E is the photon energy, $N^{\lambda L}$ is the virtual photon spectrum, and $\sigma^{\lambda L}_{\gamma,x}(E)$ is the photodisintegration cross section through a nuclear transition of multipolarity λL. Computable expressions for $N^{\lambda L}$ have been obtained by Gargaro and Onley(4) using distorted wave approximation.

It is convenient to study how the existence of a quadrupole component in the one neutron photodisintegration of ^{238}U would show up in the electrodisintegration cross section. Let us then assume that the measured (γ,n) cross section $(\sigma_{\gamma,n})$ is composed by a dipole $(\sigma^{E1}_{\gamma,n})$ plus a quadrupole $(\sigma^{E2}_{\gamma,n})$ component. Using expression (1), the electrodisintegration cross section can be evaluated by:

$$\sigma^{E1+E2}_{e,n}(E_0) = \int_0^{E_0} \left\{ \sigma_{\gamma,n}(E) N^{E1}(E_0,E) + \sigma^{E2}_{\gamma,n}(E) \left[N^{E2}(E_0,E) - N^{E1}(E_0,E) \right] \right\} E^{-1} dE \qquad (2)$$

where we have assumed:

$$\sigma^{E2}_{\gamma,n} = \sigma_{\gamma,n} - \sigma^{E1}_{\gamma,n} \qquad (3)$$

In this paper we will use for $\sigma_{\gamma,n}$ the available experimental data of Veyssière et al.[5] and Dickey and Axel[6].

To assess the sensitivity of the electrodisintegration cross section to the quadrupole strength we have evaluated expression (2) representing $\sigma^{E2}_{\gamma,n}$ with a Breit-Wigner formula of area S, peak position E_p and width Γ. We have used S = 35 MeV mb, which corresponds to 50% of the energy-weighted sum rule (EWSR)[7], Γ = 3 MeV, a typical width for high Z nuclei[8] and E_p = 10 MeV, in accordance with the observed $63/A^{1/3}$ dependence for the excitation energy of the GQR[9].

We then compare the evaluated $\sigma_{e,n}^{E1+E2}$ with the expected electrodisintegration cross section in the case of a pure *E1* process ($\sigma_{e,n}^{E1}$), which is evaluated setting $\sigma_{\gamma,n}^{E2} = 0$ in expressions (2) and (3). In Fig.2 the ratio of the calculated cross sections $\sigma_{e,n}^{E1+E2}$ and $\sigma_{e,n}^{E1}$ is shown.

The assumed $\sigma_{\gamma,n}^{E2}$ has a small peak cross section of 7.4 mb as compared with the measured $\sigma_{\gamma,n}$ which is 192.0 ± 7.1 mb[5] at 9.95 MeV of excitation energy and has an integrated strength of only 3 percent of the measured $\sigma_{\gamma,n}$ integrated strength[10]. As it can be seen from Fig. 2, this $\sigma_{\gamma,n}^{E2}$ that would be very difficult to identify in (γ,n) measurements, has a considerable contribution in $\sigma_{e,n}$. At 25 MeV it contributes with 50% to the electrodisintegration cross section.

III. MEASUREMENTS AND ANALYSIS

Very thin uranium targets (thickness of the order of 10^{-5} radiation lengths, placed in a vacuum chamber, were bombarded in the electron linear accelerator of

Universidade de São Paulo. The electron flux was measured in a Faraday Cup. The amount of ^{238}U in the targets was determined by α spectroscopy. The cross section was obtained by measuring the activity of the 59.5 KeV γ-ray line from the 6.75 days decay of ^{237}U using a Ge-Li low energy photon spectrometer system. A typical pulse hight spectrum is shown in Fig.3.

In Fig.4 the experimental cross section for the reaction $^{238}(e,e',n)^{237}U$, as a function of the electron incident energy, is shown as full circles. The errors indicated include the statistical uncertainties of the measured quantitites and the estimated contributions arising from electron flux measurements, target non uniformity and target positioning relative to the electron beam and detector. The point at 6.0 MeV is an upper limit. The full curve is the predicted electrodisintegration cross section for a pure *E1* process ($\sigma^{E1}_{e,n}$) obtained using $\sigma_{\gamma,n} = \sigma^{E1}_{\gamma,n}$ in expressions (2) and (3). In Fig.5 the ratio of our experimental data to the predicted $\sigma^{E1}_{e,n}$ is shown by the points. The errors refer only to the uncertainty of our experimental points. This ratio shows no evidence of an increase with the electron incident energy that is expected in the case of significant *E2* contribution. Actually, the best straight line fit to the points, shown by the full curve yields a negligible slope, leading to a constant ratio with value 1.038 ± 0.009. Our results are 4% higher than those obtained from the $\sigma_{\gamma,n}$ data and can be interpreted as a very good agreement between two absolute values of the same physical quantity measured by different methods. The difference is well within quoted errors. Hereafter we have divided our experimental values by 1.038 to merge both absolute measurements.

In order to establish an upper limit to the E2 contribution allowed by our data, we carried out a least squares fit to the experimental data, using expression (2) and representing $\sigma^{E2}_{\gamma,n}$ by a Breit-Wigner formula with $E_p = 10$ MeV, $\Gamma = 3$ MeV and variable S. The best fit is obtained for $S = 0$ corresponding to $\sigma^{E2}_{\gamma,n} = 0$. At the 95% confidence level the integrated $\sigma^{E2}_{\gamma,n}$ exhausts 8% of the EWSR. This upper limit corresponds to only 0.25% of the $\sigma_{\gamma,n}$ integrated cross section[10].

IV. DISCUSSION

Our results show that no neutron emission from 2^+ states is observed, setting a small upper limit for this decay. This is rather unexpected, since, from statistical considerations, a large fraction of the GQR should decay through this channel.

Evidence of the selectivity of the decay mode on the multipolarity of the excited resonance is already contained in some available experimental data as presented below.

According to Hanna[11], (γ,α_0) cross sections, measured through the inverse capture reaction (α,γ_0), show that alpha emission is 10 times more probable by *E2* than by *E1* absorption.

Recently, Wolynec, Martins and Moscati[3] have shown, by measuring the cross section for $^{238}U(e,e',\alpha)^{234}Th$, that the (γ,α) reaction proceeds dominantly through *E2* transitions. Using a virtual photon analysis, it was shown that the amount of absorbed *E2* strength used for the (γ,α) reaction exhausts 50% of the EWSR. These data locate $\sigma^{E2}_{\gamma,\alpha}$ at the excitation energy of 9 MeV, with a width of 3.7 MeV (FWHM).

Preliminary data on the absolute electrofission cross section and the angular distribution of fission fragments in ^{238}U, indicate that a significant fraction of the EWSR is exhausted by this channel, the quadrupole component being concentrated around 10 MeV[12].

The (e,e',α) and (e,e',f) results indicate that for ^{238}U the dominant modes of decay of the GQR are the alpha and fission channels.

We would like to discuss the compatibility of the above reported evidence with the only available data on electric quadrupole absorption by ^{238}U.

Lewis and Horen[13] observed a ressonance in (p,p') inelastic scattering from ^{238}U, in the energy region 10-14 MeV, tentatively assigned as *E2*, exhausting $(85\pm50)\%$ of the EWSR. No structure was seen below 10 MeV.

In Fig.6 we reproduce the experimental data on $^{238}U(e,e',\alpha)^{234}Th$ cross section. Curve (a) shows the predicted electrodisintegration cross section for $\sigma^{E2}_{\gamma,\alpha}$ represented by a Breit-Wigner formula of S= 28 MeV mb, Γ = 3.7 MeV and E_p = 8.9 MeV. These parameters yield the best fit to the points[3].

Curve (b) shows the predicted electrodisintegration cross section, using for $\sigma^{E2}_{\gamma,\alpha}$ the resonance observed by Lewis and Horen with a strength which exhausts 90% of the EWSR. We have computed the reduced χ^2 value for different strengths of this resonance. In the region from 80 to 100% of the EWSR the obtained values are around 6. Outside this region we obtain significantly higher values. As it can be seen, the resonance observed by Lewis and Horen is incompatible with the (e,e',α) data. The impossibility of improving the fit by changing the strength is related to the sensitivity of the fit on the peak position of the *E2* resonance. It is impossible to fit the electrodisintegration results with a resonance that has negligible strength below 10 MeV.

V. CONCLUSIONS

The electrodisintegration absolute cross section measurements $^{238}U(e,e',n)^{237}U$ performed in this work show that the one neutron emission proceeds exclusively through *E1* absorption. We have set un upper limit to *E2* transitions of only 0.25 percent of the *E1* transitions in this channel.

This result associated with the *E2* character of $^{238}U(e,e',\alpha)^{234}Th$ and other experimental evidences reveal the existence of a decay mode selectivity on the spin and parity of the excited giant resonance.

Other nuclei and decay channels are being investigated using this method in order to verify if the strong selectivity observed in ^{238}U is extensive to other nuclei.

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FIGURE CAPTIONS

FIG.1 - Electric dipole and quadrupole virtual photon spectra for electrons of kinetic energy 24.5 MeV, scattered by a uranium nucleus.

FIG.2 - Ratio of the calculated cross sections $\sigma_{e,n}^{E1+E2}/\sigma_{e,n}^{E1}$ versus electron kinetic energy. $\sigma_{e,n}^{E1+E2}$ is obtained by assuming that the measured(γ,n) is composed by a GDR plus a GQR which exhausts 50% of the EWSR. $\sigma_{e,n}^{E1}$ is obtained by assuming the measured (γ,n)to be a pure E1 process.

FIG.3 - Typical pulse height spectrum showing the 59.5 KeV γ-ray line from the 6.75 days decay of ^{237}U.

FIG.4 - Experimental cross section for the reaction ^{238}U(e,e',n)^{237}U, versus electron kinetic energy. The point at 6.0 MeV is un upper limit to the cross section. The full curve is the predicted electrodisintegration cross section for a pure E1 process. No free parameters adjusted.

FIG.5 - The ratio of our experimental cross section to the predicted cross section for a pure E1 process is shown by the points. The full curve shows the best straight line fit to the points.

FIG.6 - Experimental cross section for the reaction $^{238}U(e,e',\alpha)^{234}Th$ from ref.[3]. Curve (a) shows the predicted electrodisintegration cross section for $\sigma_{\gamma,\alpha}$ being a pure E2 process and represented by a Breit-Wigner with S = 28 MeV mb, E_p = 8.9 MeV and Γ = 3.7 MeV(see ref.[3]) .Curve (b) shows the predicted electrodisintegration cross section using for $\sigma_{\gamma,\alpha}$ the E2 resonance from ref.[18] with a strength of 90 percent of the EWSR, which leads to the lowest reduced χ^2. The reduced χ^2 of both curves to the experimental data are indicated.

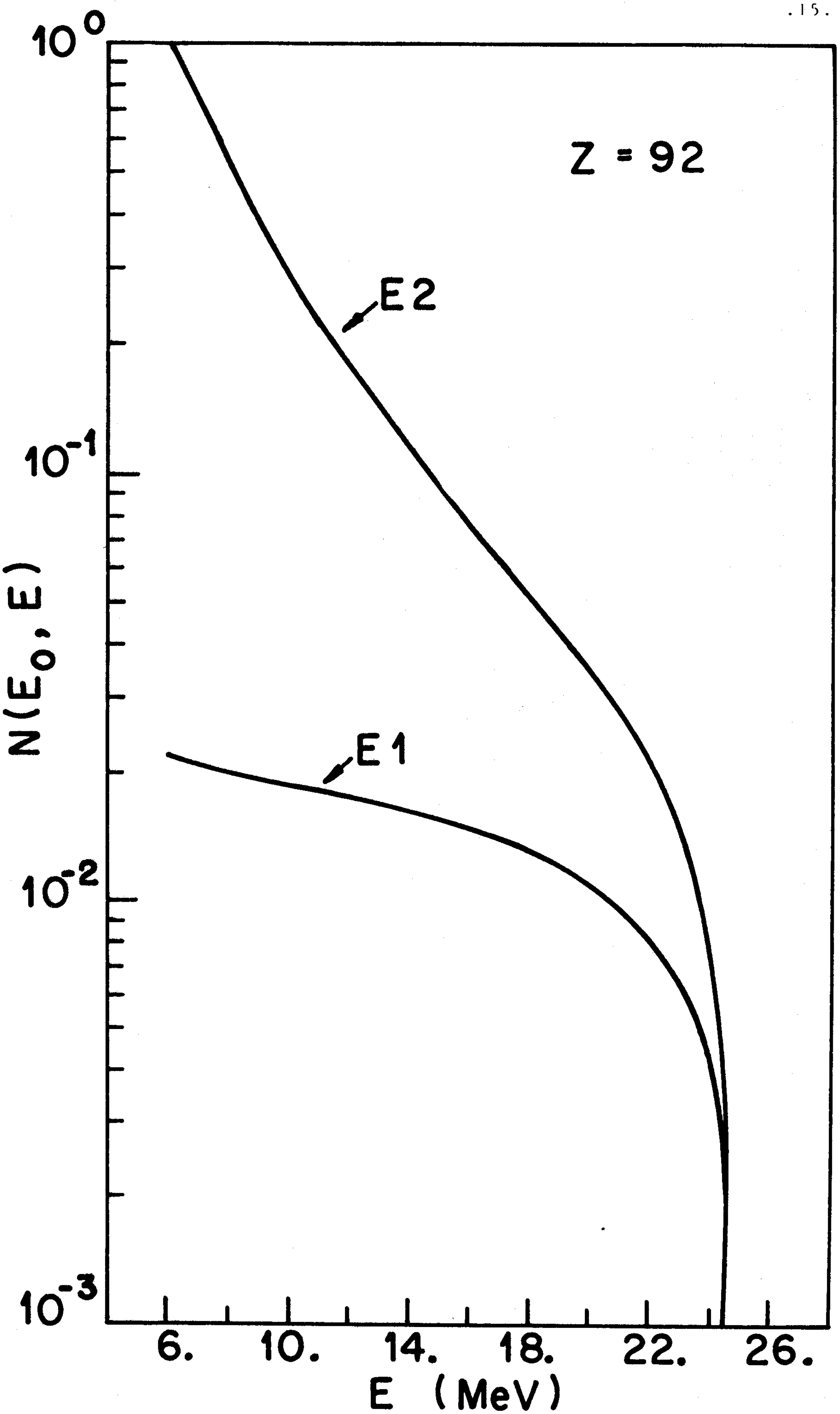


Fig.1

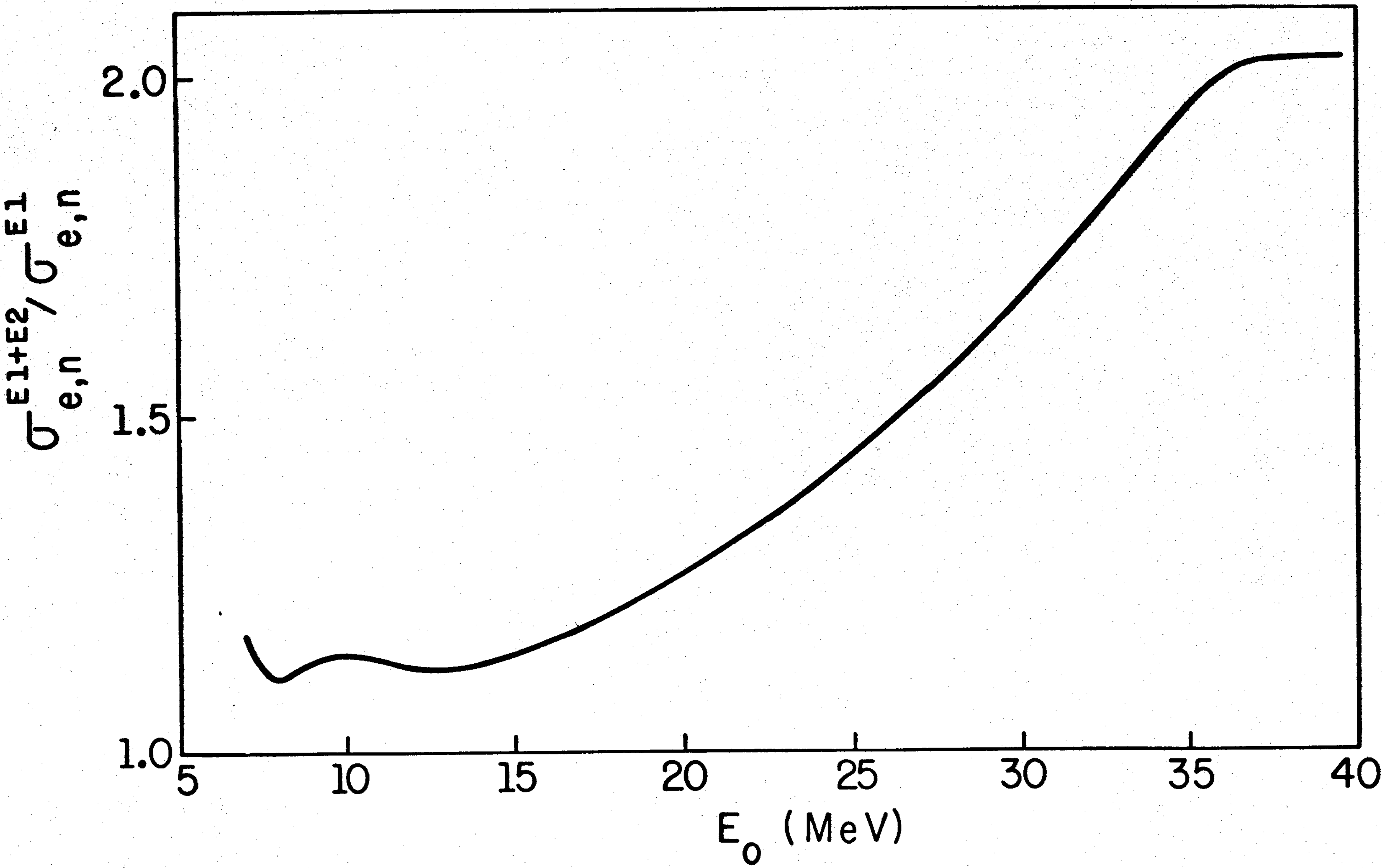
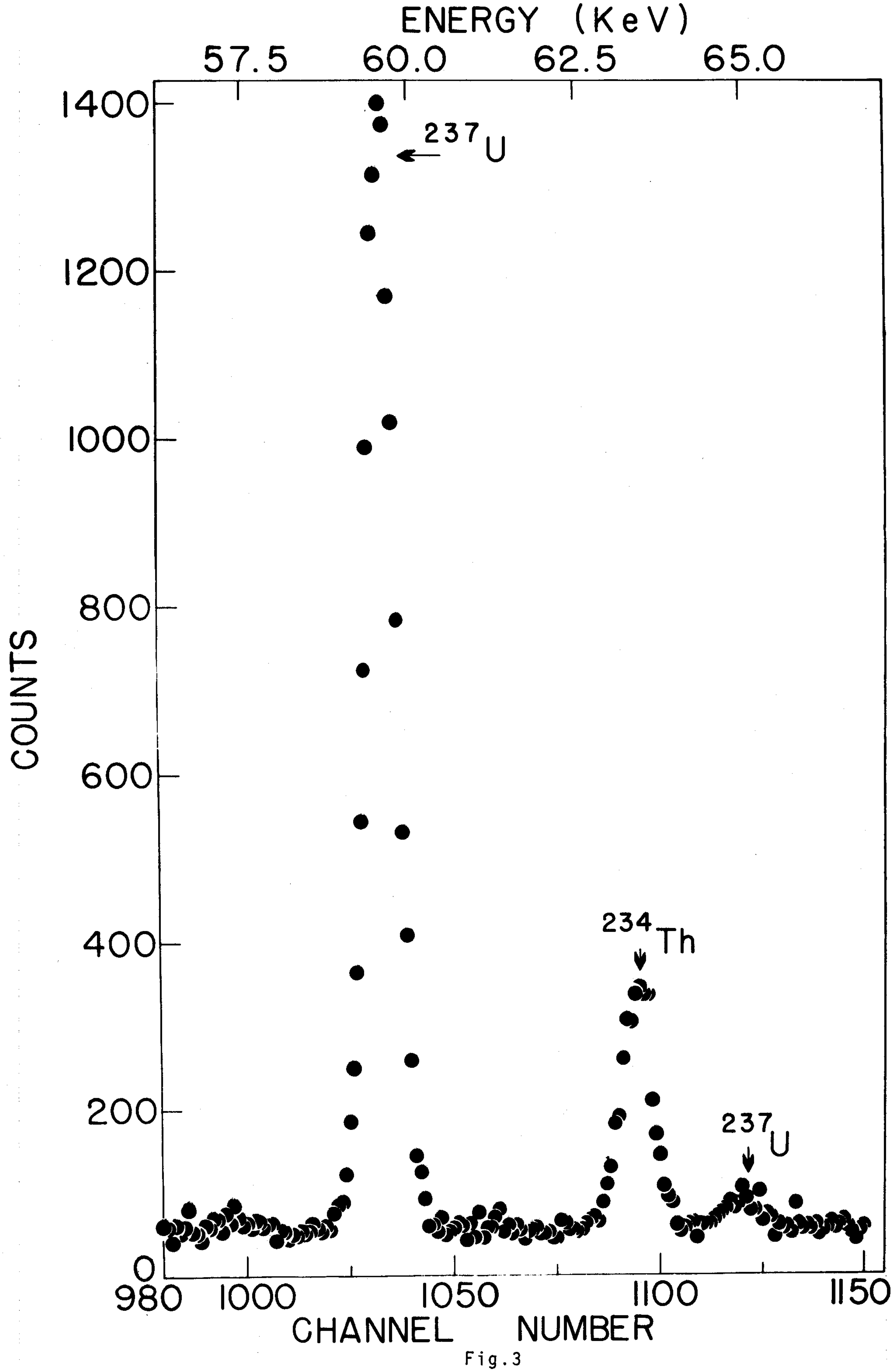


Fig.2



ENERGY (KeV)
57.5
60.0
62.5
65.0
1400
1200
1000
800
600
400
200
0
COUNTS
237U
234Th
237U
980
1000
1050
1100
1150
CHANNEL NUMBER

Fig.3

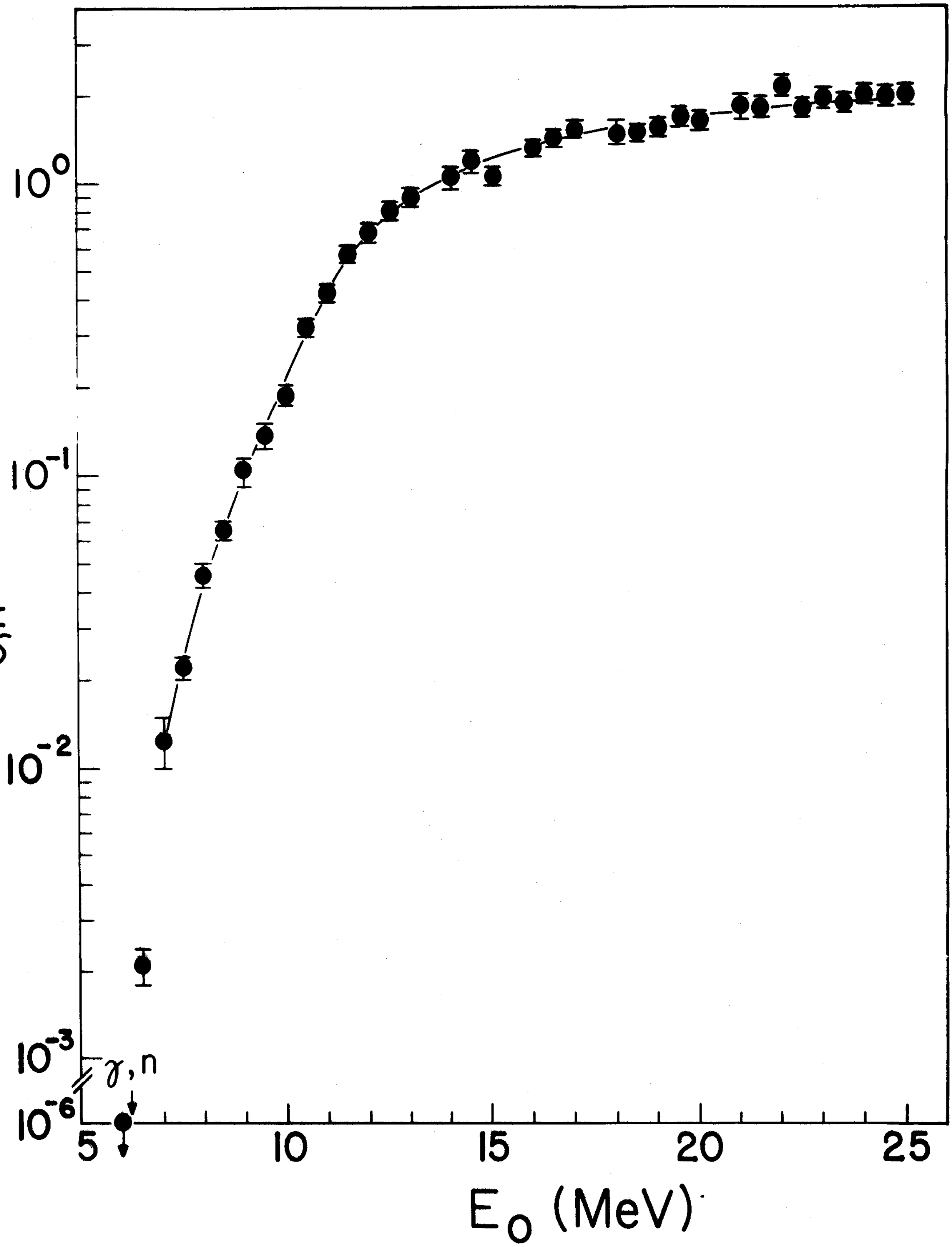


Fig. 4

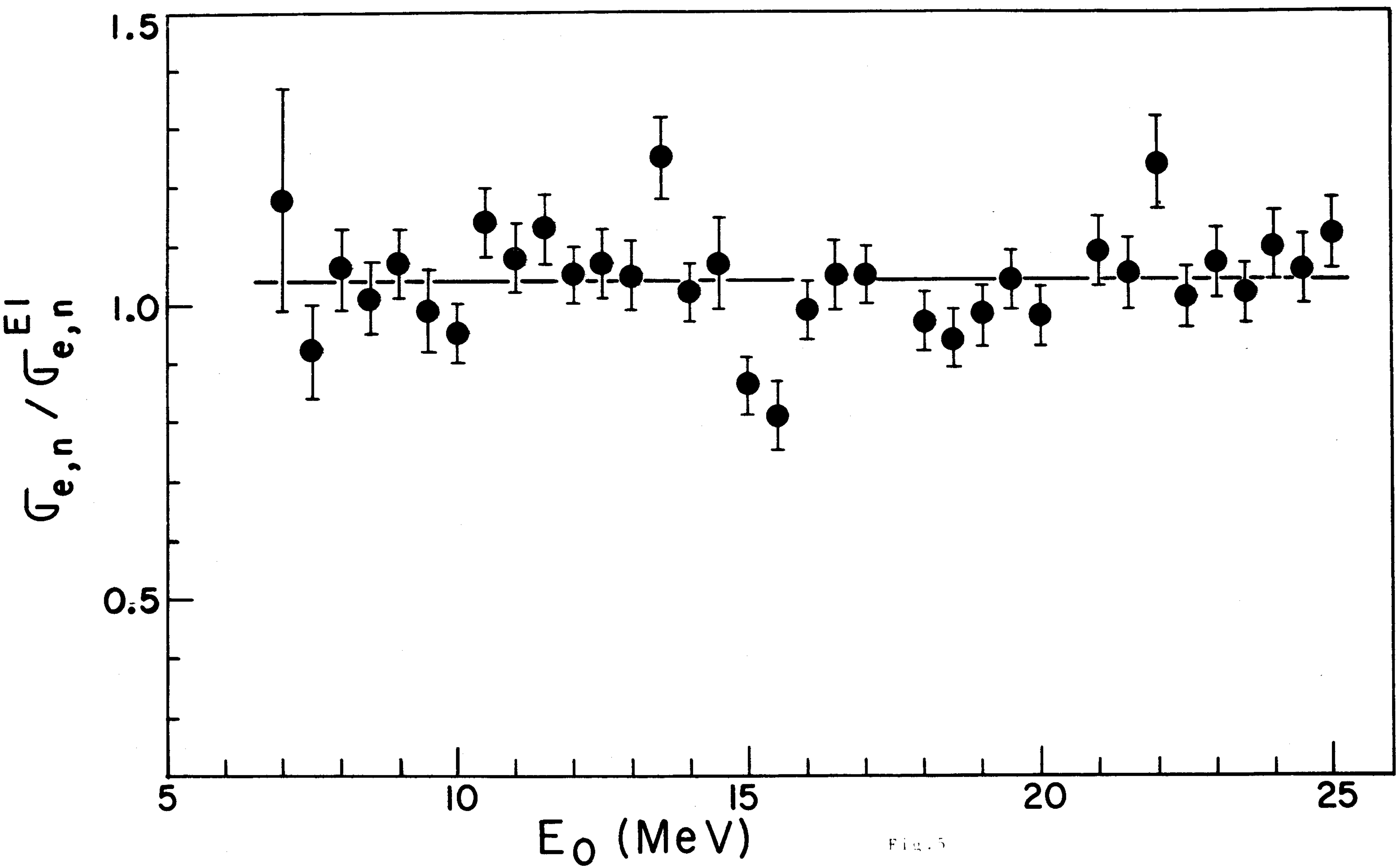


Fig.5

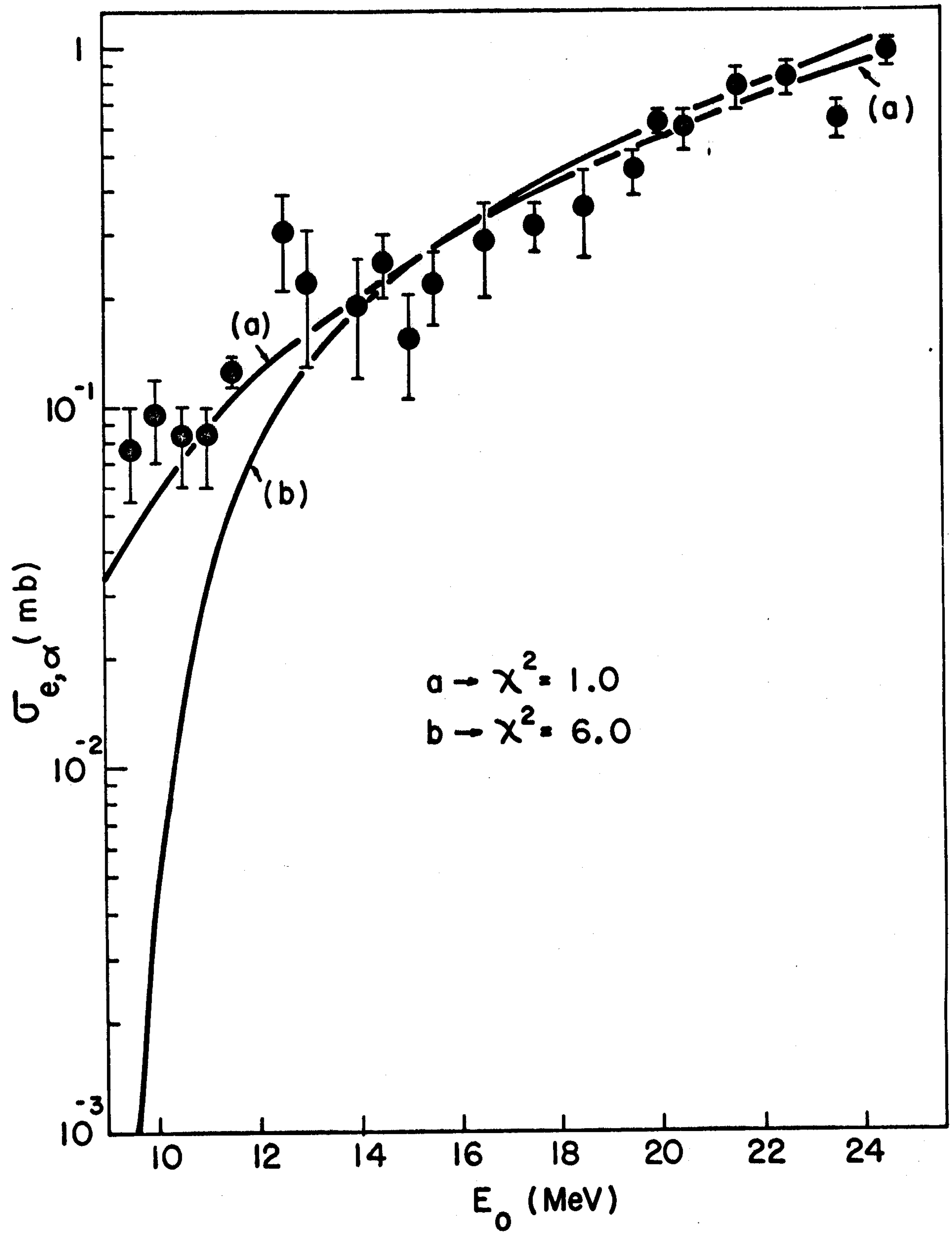

1
10^{-1}
10^{-2}
10^{-3}
$\sigma_{e,\alpha}$ (mb)
10
12
14
16
18
20
22
24
E_0 (MeV)
(a)
(b)
(a)
a → χ^2 = 1.0
b → χ^2 = 6.0

Fig.6