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ABSORPTION AND FISSION CROSS SECTIONS OF 49 IN THE NEUTRON ENERGY RANGE 0.01 ev TO 100 ev

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ABSTRACT

Measurements have been made of the variation of the fission cross section of 49, $\sigma_f(49)$ with neutron energy for the region from 0.02 ev to 450 ev and of the variation of the absorption cross section, $\sigma_a(49)$, in the region 0.01 ev to 50 ev. Neutron energies were determined by use of the slow-neutron velocity spectrometer. The fission and absorption cross section curves appear qualitatively to be quite similar.

Three resonances were observed. One, which has been previously reported (LA-91), is at 0.295 ev, a second at about 12 ev and a third at about 60 ev. The first two were observed both in fission and absorption, the third in fission only since the absorption data do not extend to high enough energy.

The quantity $1+\alpha(49) = \sigma_a(49)/\sigma_f(49)$ in the region between 0.0250 ev and 1 ev was computed from the measurements. It deviates from its value at 0.0250 ev by an amount between one and two times the estimated probable value. Since the estimation of the probable error is rather difficult it is not possible to say whether α does or does not vary in this region.

It was found impossible to fit the resonance at 0.295 ev with a Breit-Wigner one-level formula. The possible significance of this fact and of the behavior of $1+\alpha(49)$ is discussed.

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ABSORPTION AND FISSION CROSS SECTIONS OF 49 IN THE NEUTRON ENERGY RANGE 0.01 ev TO 100 ev

Introduction

Several groups of experimenters have measured the thermal fission cross section of 49, $\sigma_f(49)$, by comparing the counting rate in a 49 fission chamber to that in a 25 fission chamber. The accepted value[1] of $\sigma_f(49)$ at 0.0250 ev is 705 barns. Preliminary measurements on the absorption cross section of 49, $\sigma_a(49)$, as a function of neutron energy in the region 0.01 ev to 3.0 ev have been reported[2]. These measurements disclosed the presence of a strong absorption resonance at 0.3 ev, indicated that this resonance was present also in the fission cross section, and gave the value 1057 ± 25 barns for $\sigma_a(49)$ at 0.0250 ev. The experiments to be described in this report were carried out for the following reasons. More 49 was available so that the absorption measurements could be extended to about 50 ev. Thin 49 metal absorbers had been fabricated by the Metallurgy Department so that it was possible to examine the 0.3 ev resonance in σ_a more closely. It was found possible to put sufficient 49 in a fission chamber to be able to measure the variation of $\sigma_f(49)$ with the energy up to several hundred electron volts and so obtain an indication of the dependence of $1+\alpha(49) = \sigma_a(49)/\sigma_f(49)$ on neutron energy.

Fission Experiment

The variation of the fission cross section of 49, $\left(\sigma_f(49)\right)$, with energy has been measured for the region from 0.02 ev to 450 ev by use of the slow neutron velocity selector. This variation is measured by the previously described method of comparing the counting rate in the modulated neutron beam for a 49 chamber to that for a BF_3 chamber[3].

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1) Handbook LA-140.

2) LA-91.

3) LA-82.

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The chamber used here has been described in LA-158 and is shown in Fig. 1a in this report. It consists of three sections; the first and third section contain 49 foils and the center section is filled with BF_3. The beam passes through the first 49 section, then the BF_3 section and finally the second 49 section. Thus the neutron spectrum seen by the BF_3 chamber is almost exactly the same as the average spectrum seen by the 49 chambers even though there may be some absorption in the plates separating the chambers. Also the geometrical center of the BF_3 chamber is in the same place as the average center of the 49 chambers. An added advantage of this chamber is that alternate BF_3 and 49 runs can be taken without the necessity of moving the chambers. The 49 used in the fission chambers was deposited on four foils to a thickness of less than 0.3 mg per cm^2. One chamber contained 28 mg, the other 29 mg. Each section of the 49 chamber contained two 49 foils (the two outside plates in each section shown in Fig. 1a were not used). The plates holding the foils were at high negative voltage; the collector plate was between these plates at a distance of 0.6 cm from them. In order to reduce the number of pile ups of α-particle pulses and so to be able to differentiate between α-particle pulses and fission pulses the following precautions were taken. Grids were placed over the foils. These consisted of 1/32" plates through which were dirlled such a number of 1/2" diameter holes that the transparency of the grids was about 80%. This had the effect of discriminating against those particles emitted parallel to the foil. Thus the most effective α pulses were eliminated. These grids cut down the number of fission pulses detected by about 50%. The collection time in the chamber was made as small as possible by using a mixture of argon at atmospheric pressure and about 5 cm of CO_2. Also the pulses were kept to about 0.2 μsec width by use of a delay line clipper in the grid of the first tube in the main amplifier. With these conditions it was possible to obtain a short bias plateau for the fission counts.

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The BF_3 chamber was filled with a mixture of about 3 cm of normal BF_3 and with about 60 cm of argon in order to decrease the sensitivity to a point where the counting rate was not too fast.

The actual datum taken was the ratio of C(the counts in a time-of-flight interval) to T(the number of counts due to neutrons of all energies). This was done in order to eliminate changes in sensitivity due to changes in discriminator bias and also to eliminate the dependence in sensitivity on the geometry of the chamber. The ratio R of $(C/T)_{49}$ (for the 49 fission chamber) over $(C/T)_B$ (for the BF_3 chamber) is given by $R = \left[\sigma_f(49)/\sigma_\alpha(B)\right]K$ where the cross sections are those for the time-of-flight region considered and K is a constant depending on the shape of the neutron spectrum used. Due to this dependence on spectrum the results of the experiment give only the variation of $\sigma_f(49)$ with energy, not the absolute cross section. Also when a change in spectrum was made it was necessary to measure the relative changes in total counting rate of the two chambers in order to normalize the results. The experiment was so arranged that the only normalization necessary was between the low-energy region (0.5 ev down) and the high energy region (above 0.5 ev) where Cd was used in the beam to permit a faster repetition rate. In order to obtain a high enough counting rate in the 49 chamber the data were taken with the chamber at 3 meters from the slow-neutron source. the data were obtained in the usual way by taking runs alternately with the 49 chamber and the BF_3 chamber. The unmodulated background was measured and corrected for.

Absorption Experiment

The value of $\sigma_t(49)$ as a function of energy has been measured for the region .01 ev to 50 ev by absorption. The measurement was made with the slow neutron velocity selector by the method described in report LA-91. The ratio of counts per channel to total counts with a BF_3 chamber was taken with and without 49 absorber between the

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counter and the neutron source. Also the ratio of total counts with and without absorber for a steady beam was measured for each absorber. The transmission for the time-of-flight interval considered is given by

$$\text{Transmission} = (C_A T_o / C_o T_A)\ A$$

where C_A and C_o represent the number of counts observed in the individual channel for observations respectively with and without the absorber, T_A and T_o represent the corresponding total number of counts and A represents the total transmission of the absorber. The total cross section $\sigma_t(49) = \sigma_a(49) + \sigma_s(49)$ can be calculated from the relation

$$\text{Transmission} = e^{-n\ \sigma_t(49)}$$

where n is the number of atoms of 49 per cm^2 in the absorber.

The geometry used is shown in Fig. 1b. Suitable boron shielding was provided so that only the beam that traversed the absorber was allowed to enter the BF_3 chamber. The absorbers used were made of 49 metal and held in Al containers. The thickness of Al traversed by the beam was about 0.060"; blanks consisting of this thickness of Al were used in the "no absorber" runs. The absorbers were 4.00 cm^2 in area and of surface densities 0.0940, 0.2975, 0.366, 1.304 and 2.316 gm per cm^2. The absorber to be used in each region investigated was chosen so that the transmission was between 75% and 25%.

The source used in both the fission and absorption experiment depended on the energy region under investigation[3)]. In the thermal region the source was the tank filled with a water-B_2O_3 solution, in order to have as short a mean life as possible, together with a B_2O_3 absorber in order to eliminate the very low energy neutrons and so permit a faster repetition rate. In the region above thermal energy the water B_2O_3 tank was again used for fission although the intensity was lower than would be obtained

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from a paraffin source. A thick sheet of Cd was inserted in front of the detector for this region in order to eliminate thermal neutrons to permit a higher repetition rate. By using the same source both for thermal and higher-energy measurements of σ_f the normalization between the two ranges was simpler than it would have been if the paraffin source had been used for the higher energy range. For the absorption measurements above the thermal energy range the source used was paraffin + Cd.

Results

The runs taken and experimental conditions for each are shown in Table I for the fission experiment and in Table II for the absorption experiment. The results of the fission experiment are shown in Fig. 2. The points shown are the experimental points obtained. The curve has been normalized to 705 barns at 0.0250 ev. The cross section $\sigma_t(49)$ obtained from the absorption measurements is shown in Fig. 3. The dotted curve is $\sigma_a(49)$ where $\sigma_t(49) = \sigma_a(49) + \sigma_s(49)$. The value of $\sigma_s(49)$ of 9.6 barns has been used[4]. The points shown are again the experimental points. For comparison Fig. 4 shows both $\sigma_a(49)$ v and $\sigma_f(49)$ v.

Two corrections have been applied to the data. For the energy region 0.02 ev to 0.5 ev an estimated correction for mean life of the source has been made to the time of-flight (see LA-91). This correction depended on the time-of-flight and was never more than 6% for the fission data and never more than 3% for the absorption data.

The second correction was made in the region of the 0.3 ev resonance for the finite resolution used in the experiment. This correction had the effect of increasing the value of the cross section at resonance by about 10% for $\sigma_f(49)$ and by about 6% for $\sigma_t(49)$.

4) Preliminary result given by Fermi in private communication.

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The number of counts taken for each point was such that the statistical probable error associated with each point was usually less than 4%. However other errors, such as those involved in total transmission and normalization measurements, determination of weights of absorbers, etc., also enter. Consideration of all such errors lead to the following conclusions about the accuracy of the measurements. In the thermal region (.02 up to about 0.1 ev) the absorption curve is probably good to about 2.5%. Several measurements, the one reported in LA-91 as well as two not reported here, gave results varying by 3% or less from that shown in Fig. 3. The same error can be put on fission curve. In the region of the resonance (0.1 ev to 0.4 ev) the measurements by themselves are as good as those for lower energy. However errors such as are associated with total transmission of absorbers, for example, accumulate from one energy region to the next. Thus we believe the ratio of the cross section at resonance to that at 0.0250 ev is only good to ±7% for each of the fission and absorption curves. In the region of low cross section between the 0.3 ev and the 12 ev resonances the fission counting rate was small so that statistics are not so good and any background would be more important. It is felt that the fission curve here is good to about ±10%. For the absorption data in this region the transmission was generally rather high which tends to make the computed cross section inaccurate. Also in this region the scattering cross section is of the same order of magnitude as the absorption cross section. Thus percentage errors in $\sigma_a(49)$ are larger than percentage errors in the measurement of $\sigma_t(49)$. The error here is probably no less than ±20%. In the higher energy region the resolution for both measurements is poor; the fission counting rate was low; the transmission of the absorbers was too large. As a result the values here cannot be depended on to give much more than a qualitative idea as to the cross sections.

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Discussion

From the curves shown in Fig. 4 we see the following significant features. The absorption and fission measurements are qualitatively quite similar. There is the strong resonance at 0.295 ev which was reported earlier (LA-91). Two other resonances are also observed. One of these is located at about 12 volts while the other is found in the region of 60 volts. The latter resonance was observed in fission only because the absorption measurements did not extend to sufficiently high energy. The position of this resonance is not very well determined because of somewhat uncertain timing. This results from the fact that measurements were necessarily made at a short distance (3.0 m) where small absolute timing errors produce a rather large error in the energy assignment for this energy region.

From the curve we find that the absorption cross section at 0.025 ev is 1035 barns ± 25 barns. The cross section at the resonance for absorption is 5600 b ±250 b.

An attempt was made to fit both the absorption curve and the fission curve with a Breit-Wigner one level formula at the 0.3 level. The results are shown in Figs. 5 and 6. In Fig. 6 the dotted line shows the value of $\sigma_f(v)$, while the two solid lines show the results of two attempts to fit the curve. Curve C fits the experimental data in the region of maximum cross section, while curve B attempted to fit the data at both resonance and a lower energy point. In Fig. 5 the corresponding curves are shown for the absorption data. It is quite apparent that it is impossible to choose a Breit-Wigner curve which fits the level over a reasonable range of energies about the resonance. The physical interpretation of this feature is rather difficult. It is not certain that the simple Breit-Wigner formula should be expected to predict the behavior of such a complicated process as fission. However, if one does expect this formula to apply to this case, then in order to explain the observed shape of the cross section

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curves, one must assume that the cross section is the sum of two components, one of which follows the Breit-Wigner curve, while the other is some slowly varying function appearing as a background. A further discussion of this will be given below.

In the region of exact resonance, the Breit-Wigner curve which seems to fit the absorption data best has the constants, $\sigma_{max} = 5600 \pm 250$ barns, Γ (full width) = 0.097 ev. A choice of Γ which is 10% different from this one produces a fit between the experimental data and the Breit-Wigner curve which is appreciably poorer.

The ratio of the cross section for capture with emission of radiation to that for capture with fission is usually denoted by the symbol α. Since the sum of the cross sections for capture with emission of radiation and for fission is equal to the cross section for absorption, the ratio of the absorption to fission cross section is $1 + \alpha$. The experimentally determined values for $1 + \alpha$ are easily obtained from the curves of Fig. 4. In the region above 3 volts, the determination of this quantity is very poor. This is mainly due to the inaccuracy of the absorption measurements. Because of the inaccuracy in the determination of $1 + \alpha$ for the region above 3 volts, its variation for this range was not brought under consideration at all. In Fig. 7 we have plotted the value of $1 + \alpha$ from 0 to 1 ev. It is observed that it increases from about 1.5 at thermal energy to about 1.9 at exact resonance and then decreases to about 1.2 at 1 ev. In an experiment of this nature, it is quite difficult to assign the probable error which is to be associated with a given determination. However, in the region below 1 volt, the deviation of $1 + \alpha$ from a straight line is between one and two times greater than the estimated probable error. As a result, it is not possible to determine conclusively whether α does or does not vary in the interval from zero to 1 volt. Because of the possibility that α does vary in this interval, it seems worth while to consider possible interpretations of such a variation.

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One interpretation is, of course, that the cross section for capture with emission of radiation is independent of the fission cross section. Another interpretation is one proposed by Weisskopf which takes the following form. One assumes that there is more than one mode of excitation of the compound nucleus. One of these modes gives rise to a level system for which the fission width is quite narrow so that the radiative width is comparable to it. Thus for levels belonging to this mode of excitation, α would be fairly large. For levels belonging to a second mode of excitation the fission width may be quite broad compared to the radiative width so that such levels would have a very small α. The broad level having small α would appear as a "background component" while the narrow levels with large α would be superimposed on this background. Such a scheme might give rise to an observed cross section variation like that obtained. It was pointed out above, that the Breit-Wigner formula would not fit the level at 0.3 ev, and it appeared that the observed cross section might be made of two components, one of which has a narrow level at 0.3 ev and which follows the Breit-Wigner curve, while the other component is a slowly varying function of the energy. Then if we make this correlation with the proposed theory and assume that α for the level is 0.93 and that for the background is zero we should expect the observed α to vary in a manner very similar to that which is given in the Fig. 7. We then come to the conclusion that this proposed theory is not in disagreement with the measurements.

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TABLE I

Energy Region ev	On-time µsec	Frequency cps	Distance meters	Source	Symbols on Fig.
0.02 - 2.10	50	500	3	B_2O_3 tank B_2O_3 absorber	◬
0.19 - 0.522	20	500	3	B_2O_3 tank B_2O_3 absorber	⊡
0.46 - 4.73	20	2500	3	B_2O_3 tank Cd absorber	X
3.90 - 480	5	2500	3	B_2O_3 tank Cd absorber	⊙

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TABLE II

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Region ev	Abs thickness g/cm^2	On-time μsec	Frequency cycles/sec	Distance meters	Source	Symbol on Fig.
.0125 - .0406	0.2975	200	100	7.6	B_2O_3 tank	⧄
.0570 - .175	0.366	100	200	4.5	"	×
.123 - .650	0.366	50	200	4.5	"	⊙
.213 - .395	0.0940	20	200	4.5	B_2O_3 tank B absorber	Ø
.423 - 10.6	1.304	50	200	4.5	B_2O_3 tank	⊡
.468 - 4.12	3.620	20	1000	4.5	Pa Cd	▽
.75 - .915	1.304	20	1000	4.5	Pa Cd	∟
12.1 - 15.3	1.304	10	1000	4.5	Pa Cd	┘
3.80 - 77.0	3.620	10	1000	4.5	Pa Cd	△

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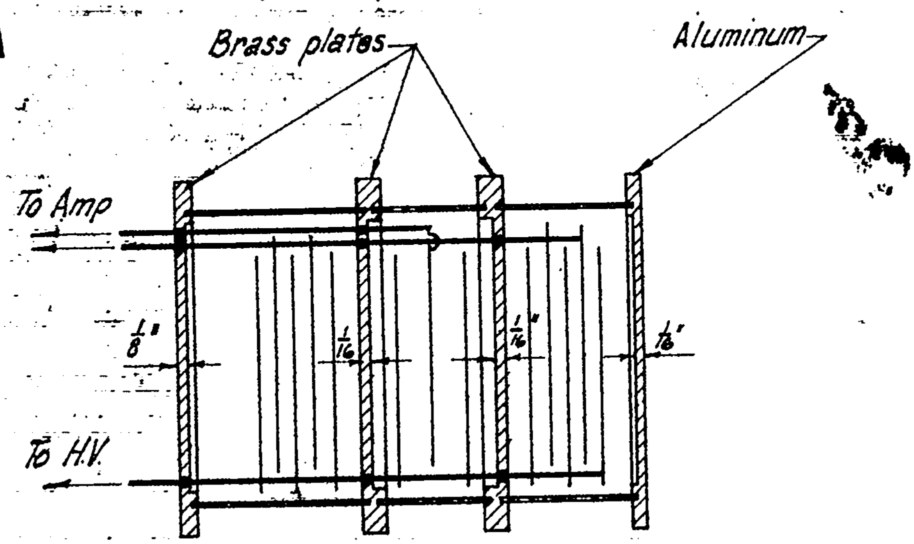

Fig. 1a
THREE-DECK IONIZATION CHAMBER
1/4" = 1"

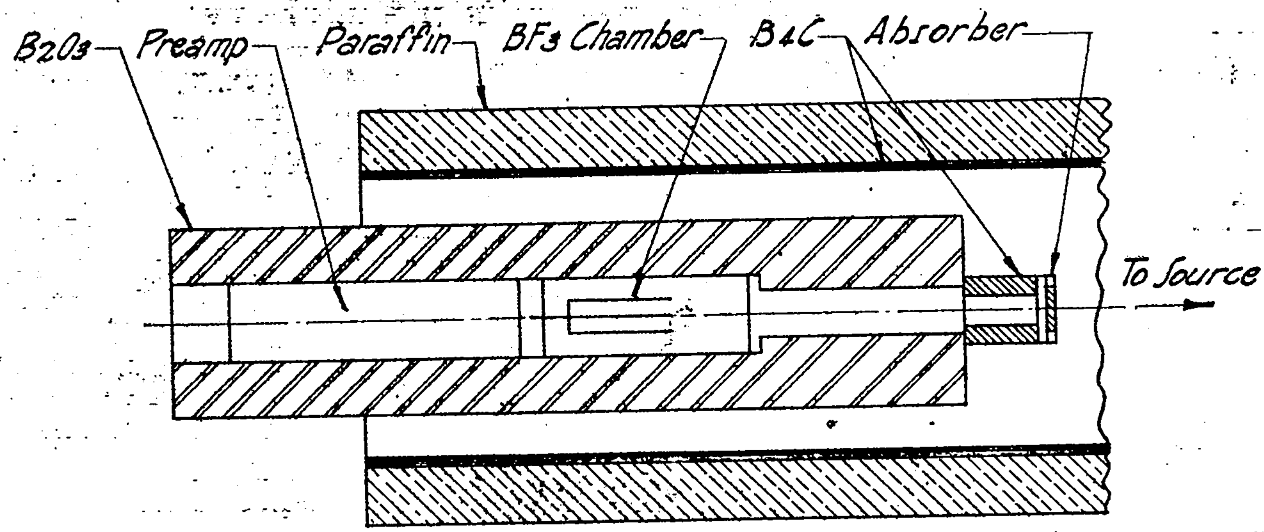

Fig. 1b
Collimator For Absorption Measurements
1/8" = 1"

LA-155 Fig 1

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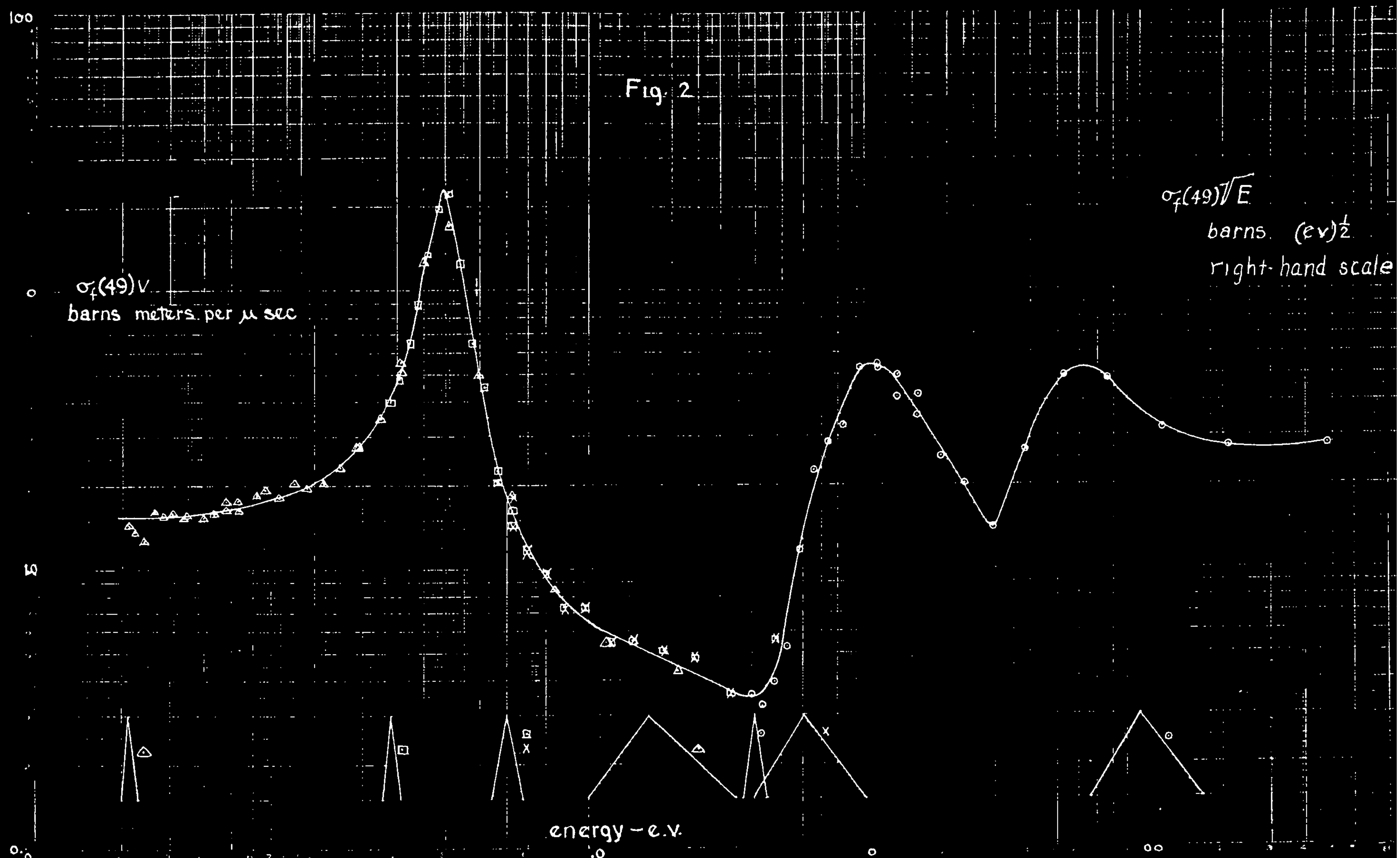
Fig. 2



$\sigma_f(49)v$
barns meters per μ sec
$\sigma_f(49)\sqrt{E}$
barns (ev)$^{\frac{1}{2}}$
right-hand scale
energy – e.v.

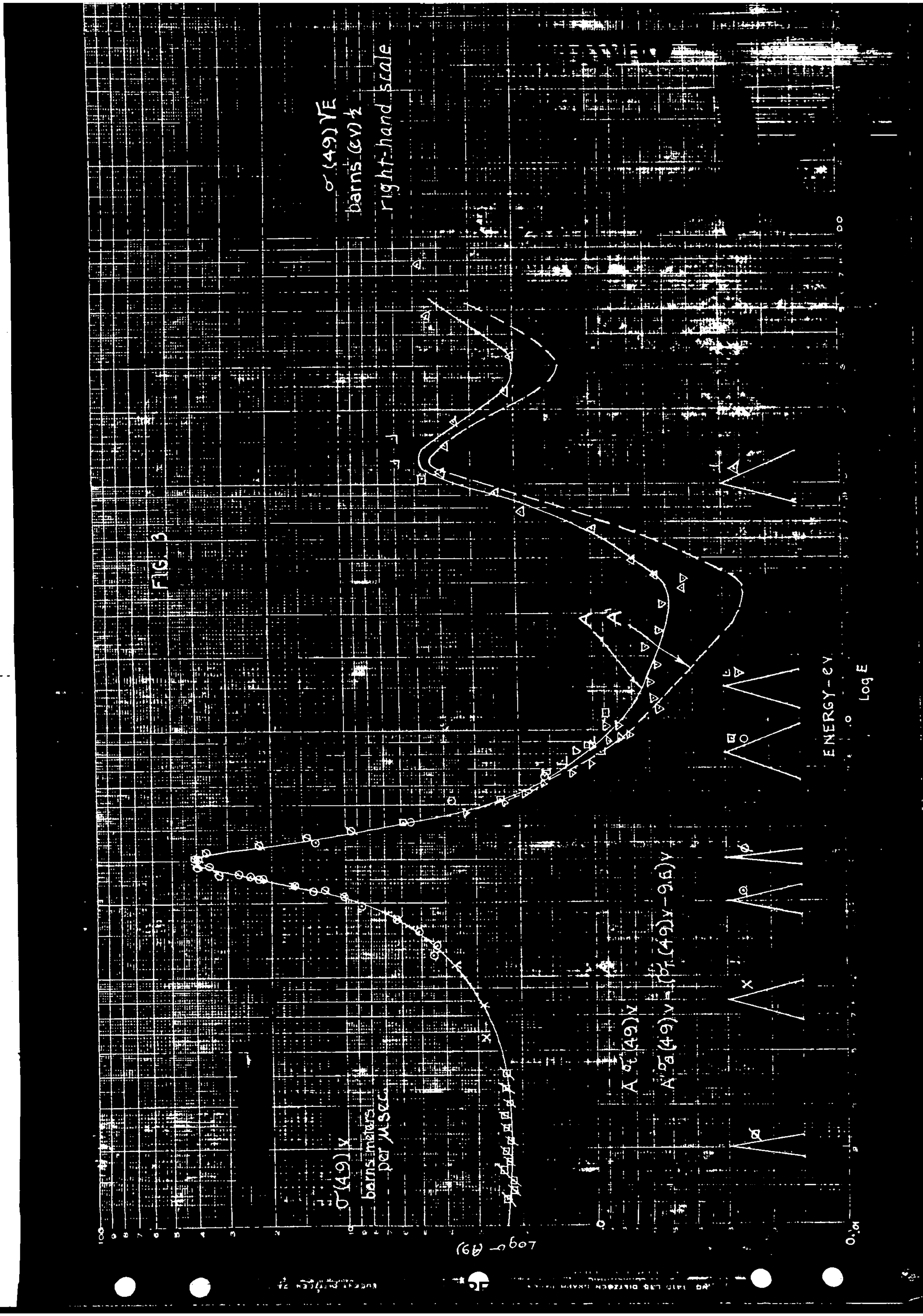


FIG. 3
σ(49)√E
barns (ev)½
right-hand scale
σ(49)v
barns meters
per μsec
A σt(49)v
A' σa(49)v = [σt(49)v - 9.6]v
ENERGY - eV
Log E
0.01
1.0
100

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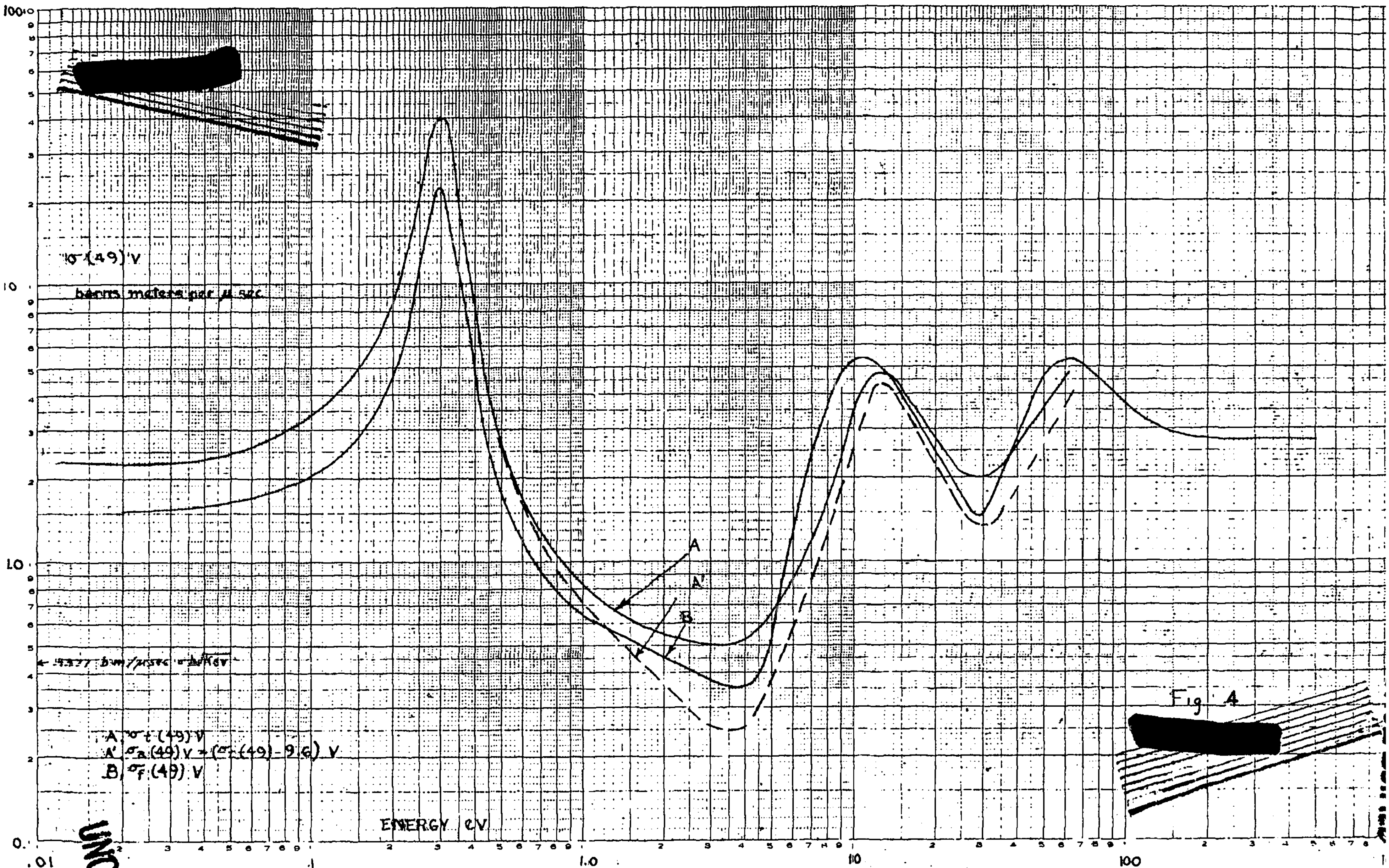

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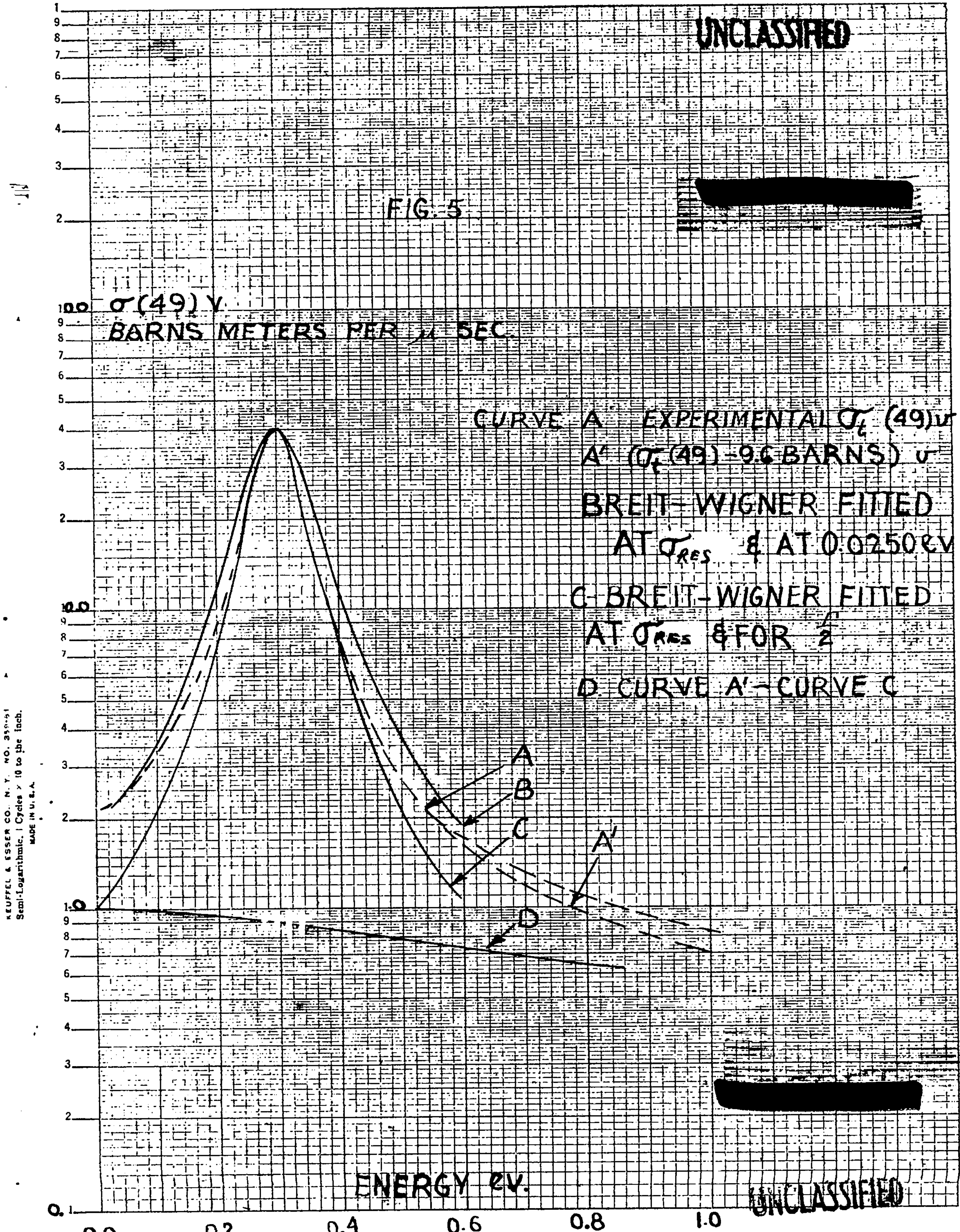
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FIG. 5
σ(49) v
BARNS METERS PER μ SEC.
CURVE A EXPERIMENTAL σt (49)v
A' (σt (49) - 9.6 BARNS) v
BREIT-WIGNER FITTED
AT σRES & AT 0.0250 eV
C BREIT-WIGNER FITTED
AT σRES & FOR Γ/2
D CURVE A' - CURVE C
A
B
C
A'
D
100
10.0
1.0
0.1
0.0
0.2
0.4
0.6
0.8
1.0
ENERGY eV.
[redacted]
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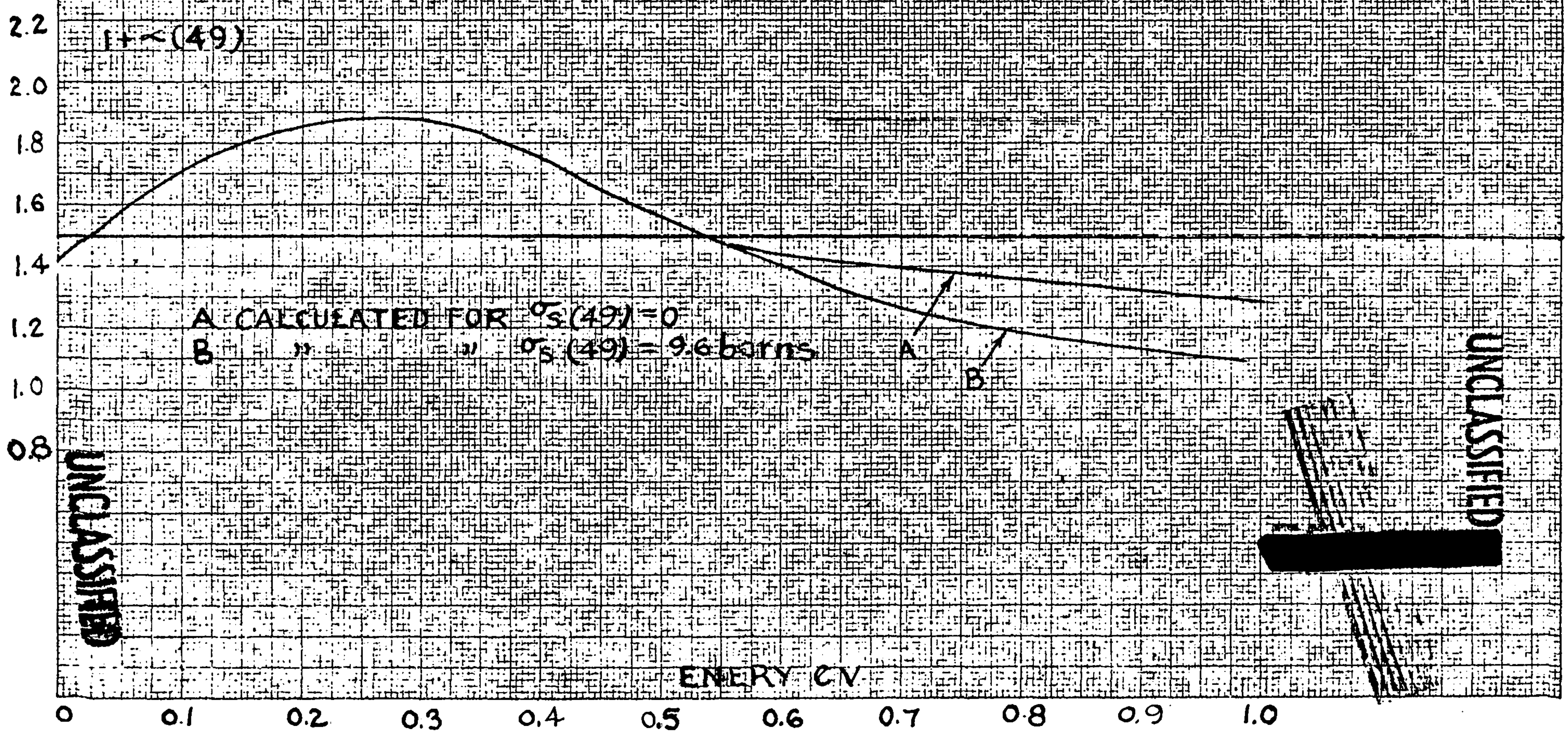
KEUFFEL & ESSER CO. N.Y. NO. 359-51
Semi-Logarithmic, 1 Cycles × 10 to the inch.
MADE IN U.S.A.

[redacted]

FIG. 7



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