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Fission Cross Section of Pu^{238} *

by

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ABSTRACT

The cross section for neutron induced fission of Pu^{238} has been measured from 0.4 to 1.4 MeV. The measurement was made by determining the ratio of the Pu^{238} cross section to that of U^{235} using a back to back gas scintillation counter. The neutrons were produced by the $Li^7(p,n)Be^7$ reaction with protons from an electrostatic generator. Preliminary results show that the cross section rises from a low value at the lowest energies to reach 2.9 barns at 1.0 MeV. Above this energy, it begins to level off as if to form the plateaux characteristic of fission cross sections in this energy region. More detailed results will be presented, and the significance of the unusually high cross section to fission systematics will be discussed.

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FISSION CROSS SECTION OF PU^{238}

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I would like to report on the measurement of the fission cross section of Plutonium-238. This is the latest in a series of measurements of fission cross sections of highly alpha-active materials. Since the technique is basically the same as that which I have described previously, I will try to be brief. In addition to describing the experiment, I will make a few remarks about how the results fit into the systematics of fission cross sections. By systematics I refer to the regular behavior of fission cross sections in the plateau region, that is between about 1 and 5 MeV.

The experiment consisted of making a ratio measurement of the Plutonium-238 cross section to that of Uranium-235. This was done using a back to back gas scintillation counter. By using a gas scintillator with highly alpha-active materials it is possible to reduce alpha pile-ups. A fast signal was taken from the photomultiplier viewing the Plutonium fissions. This was passed through a diode in such a way that the diode suppressed those alphas which came below its knee and stretched the larger pulses due to fissions. The result was that a good fission pulse spectrum could be obtained in the presence of 10^8 alphas per minute. Another sample with 4×10^8 alphas a minute gave too many pile-ups to make a satisfactory cross section normalization, but was used for shape measurements. This limit on the alpha count rate meant that the maximum amount of Plutonium which could be used in the normalization measurements was 5 micrograms.

The neutrons for the experiment were produced by the $Li^7(p,n)Be^7$ reaction using protons from a Van de Graaff accelerator. In order to produce a useable fission count rate it was necessary to maximize the neutron source strength. To do this, the counter was placed close to the source, and lithium targets were used which ranged from 40 to 70 keV thickness for 2 MeV protons. It was also necessary to use the maximum possible proton beams. To prevent hot spots the beam was scanned electrostatically over a 1/4 inch square area. With this provision it was possible to use 25 microamperes on targets with 10 mill tantalum backings.

Turning next to the fissionable samples used, the uranium sample was prepared by quantitative electro-deposition. The Plutonium was prepared by evaporation of an ethylene glycol solution. Its mass was determined by alpha counting with a calibrated low geometry counter.

Figure 1: Here are the results of the measurement. The solid black points were taken with the 4.7 microgram Plutonium sample and were used for the normalization of the cross section. The white points, some of which were taken with heavier samples, were used only for measurement of the shape. The abstract gives the value 2.9 barns at 1.0 MeV. With more complete data, we now report 2.6 barns at 1.0 MeV. The cross

section has the shape typical of a threshold fission reaction. This is what one would expect from an even massed Plutonium isotope. An unusual feature of the data is that the low energy portion does not appear to approach zero. However, measurable fissionability below threshold should not be a great surprise. It is known that Plutonium-238 has an 18 barn thermal fission cross section. It is therefore quite possible that it is detectably fissionable at all energies. The data shown here below 200 keV was taken with broad energy resolution. More measurements, with improved energy resolution will be necessary before we can determine the exact behavior below threshold.

The accuracy of the shape measurement can be judged by the scatter of points. The accuracy of the absolute normalization depends primarily on three things; the accuracy of Plutonium mass determination, the accuracy of the comparison of the Uranium and Plutonium fission pulse spectra, and the accuracy of the Uranium-235 cross section. Combined, these result in a statistical R.M.S. error of about 8%.

With cross sections like this we speak of a plateau in the region above the initial rise. This plateau usually extends upward in energy until the onset of second chance fission. It would be appropriate while considering Fig. 1 to notice that the choice of the value of the cross section in the plateau region is somewhat arbitrary. As the present measurements show, there are almost always small variations over this region. It is necessary therefore to expect differences as large as 20% between the values for plateau cross sections chosen by different individuals.

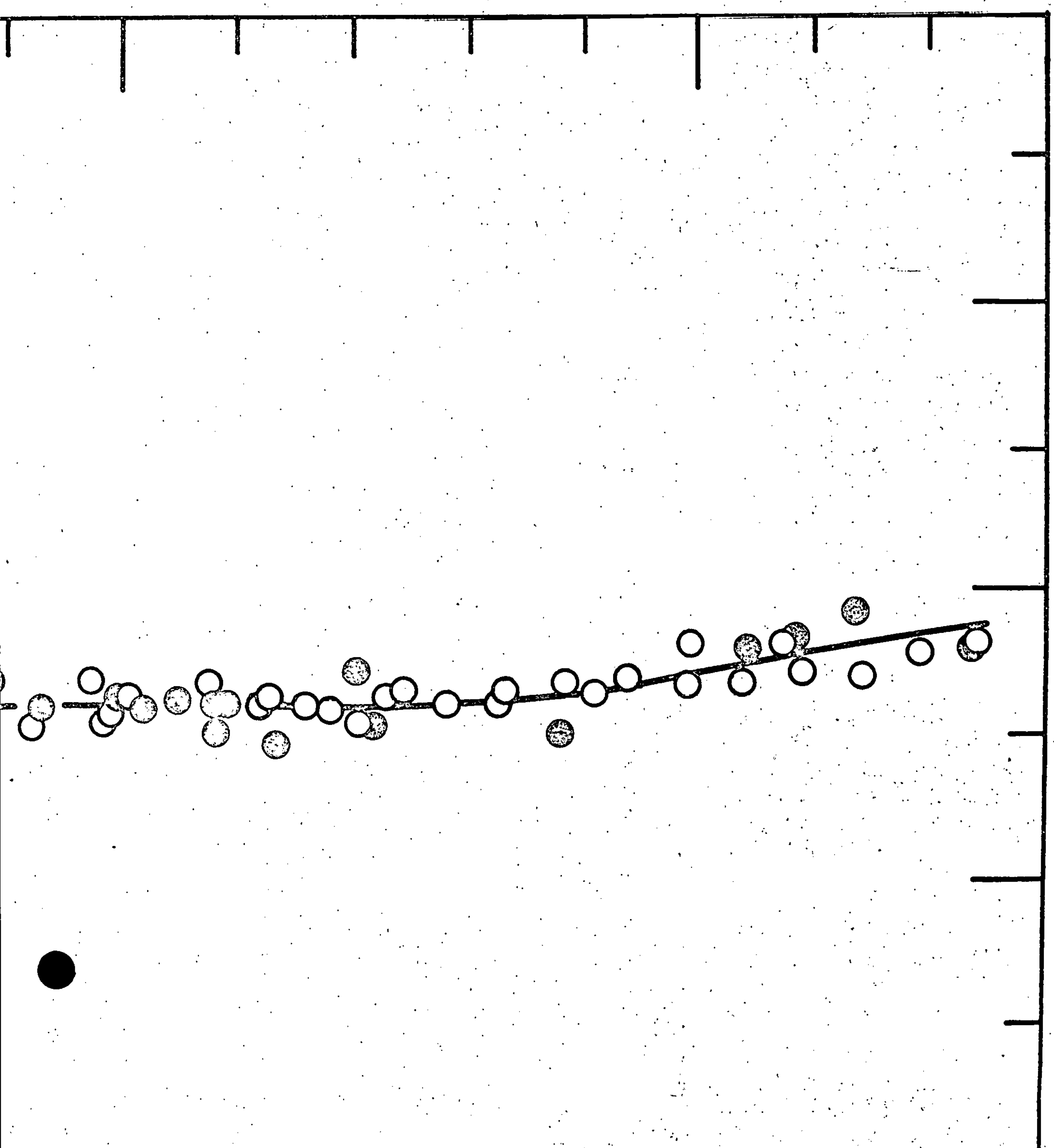
With this warning in mind let us turn to the next figure. Fig. 2: This is a plot of plateau fission cross sections against the fission parameter Z^2/A. The numbers along the points give the masses of the compound nuclei involved. The lines have been drawn arbitrarily to show how much regularity exists between the cross sections. I should add that in several instances, notably Np^{237} and Am^{241}, it was necessary to choose between quite different values obtained by different experimenters. However, in no instance was it necessary to reject the more carefully obtained data.

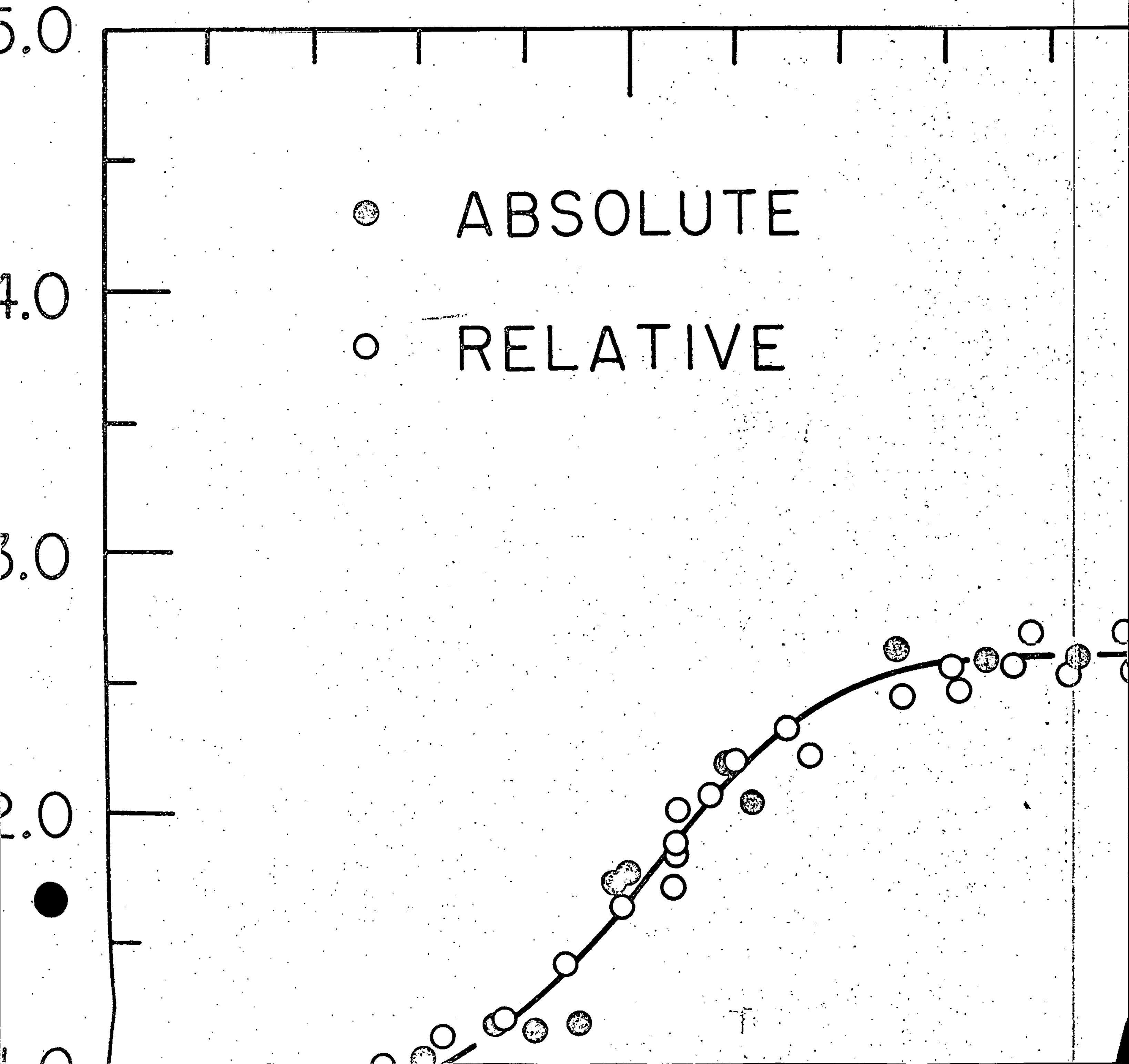
As far as the Plutonium-238 cross section is concerned, it fits this plot quite well.

The parallelism and regular spacing of these lines indicate the likelihood of the possibility of finding a different combination of Z and A which would result in a single curve for all the cross sections. Henkel, at Los Alamos, has made a search for such a parameter using what he considers to be only the best known cross sections. He concludes that by using the parameter $Z^2/A^{3/2}$ the best known cross sections fall satisfactorily close to a single line. In order to examine the fit of the Henkel formula to our Plutonium-238 data, I have plotted it on the next figure.

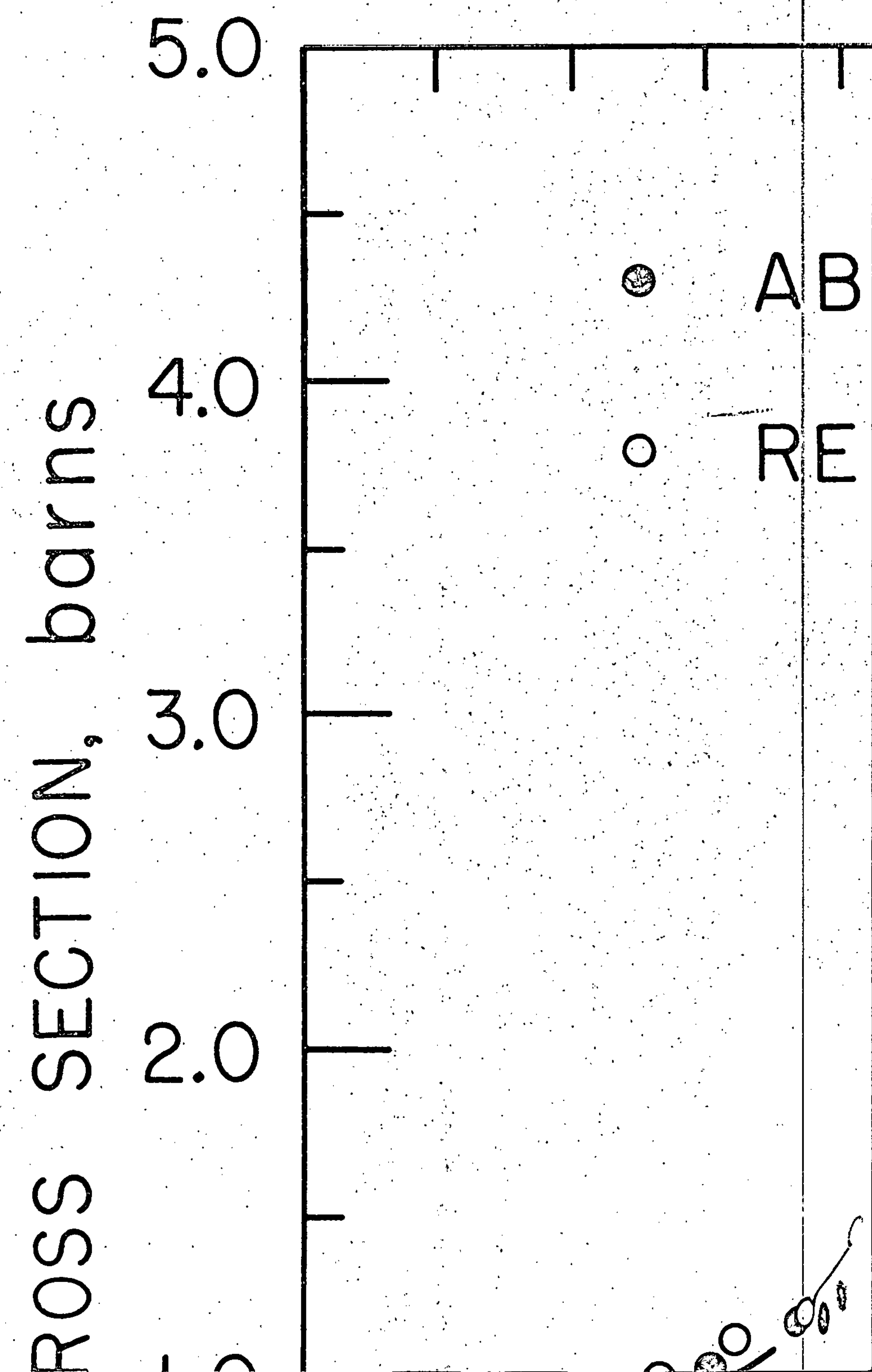
Figure 3: Here is Henkel's formula in the upper left corner. The figure is identical to the last one except instead of curves following the data, the lines are those given by Henkel's formula. Plotting the formula which depends on $Z^2/A^{3/2}$ against Z^2/A produces the family of lines shown. They are actually curved, but not sufficiently so to show on the figure. You can see that the agreement between the lines and points is quite good for the best known Thorium, Uranium, and Plutonium data. However, the Americium data is in serious disagreement. Our Plutonium-238 point up on top also disagrees by more than one would expect judging from the agreement of the other cross sections.

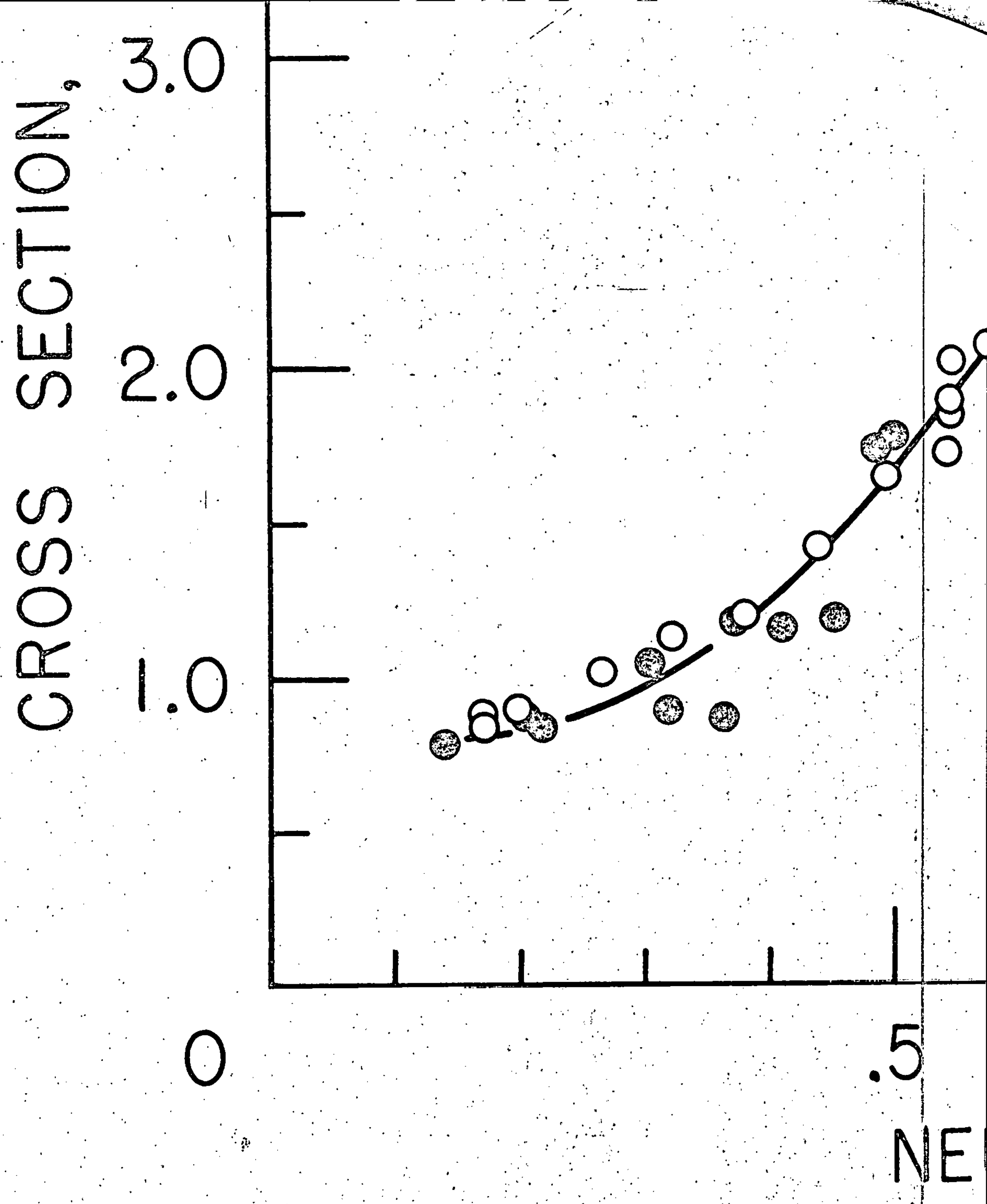
Actually, one should not be too surprised at this disagreement. It is true that this regular behavior of the plateau fission cross sections can be predicted by liquid drop model considerations. However, these considerations do not take into account peculiarities of the individual nuclei. It is therefore more appropriate to use the regular behavior of the cross section as an approximate guide rather than an absolute rule. As such, the behavior is a surprisingly good basis for evaluating measurements once they are made and for predicting cross sections as yet unmeasured.





5.0
4.0
3.0
2.0
ABSOLUTE
RELATIVE


5.0
4.0
3.0
2.0
AB
RE
ROSS SECTION, barns


CROSS SECTION,
3.0
2.0
1.0
0
.5
NE

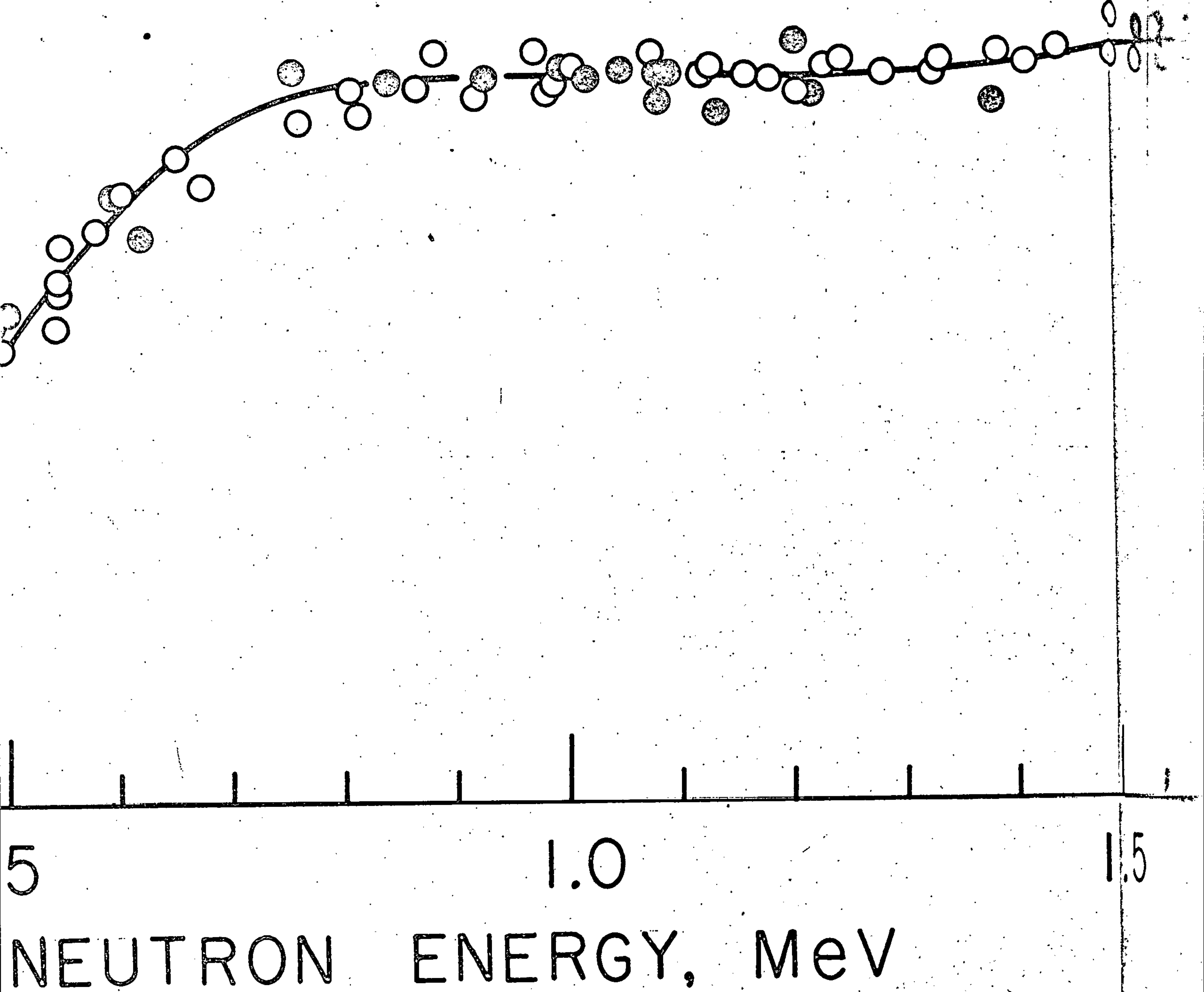
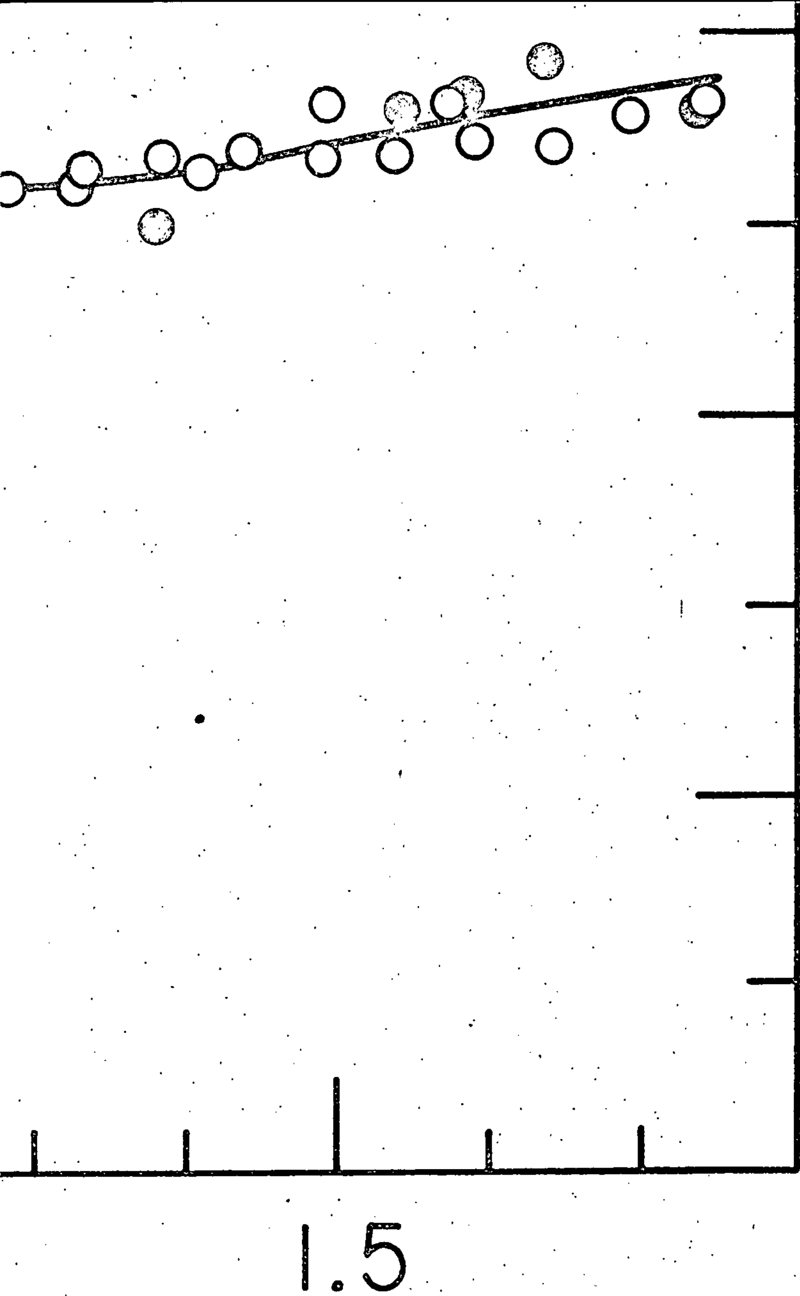
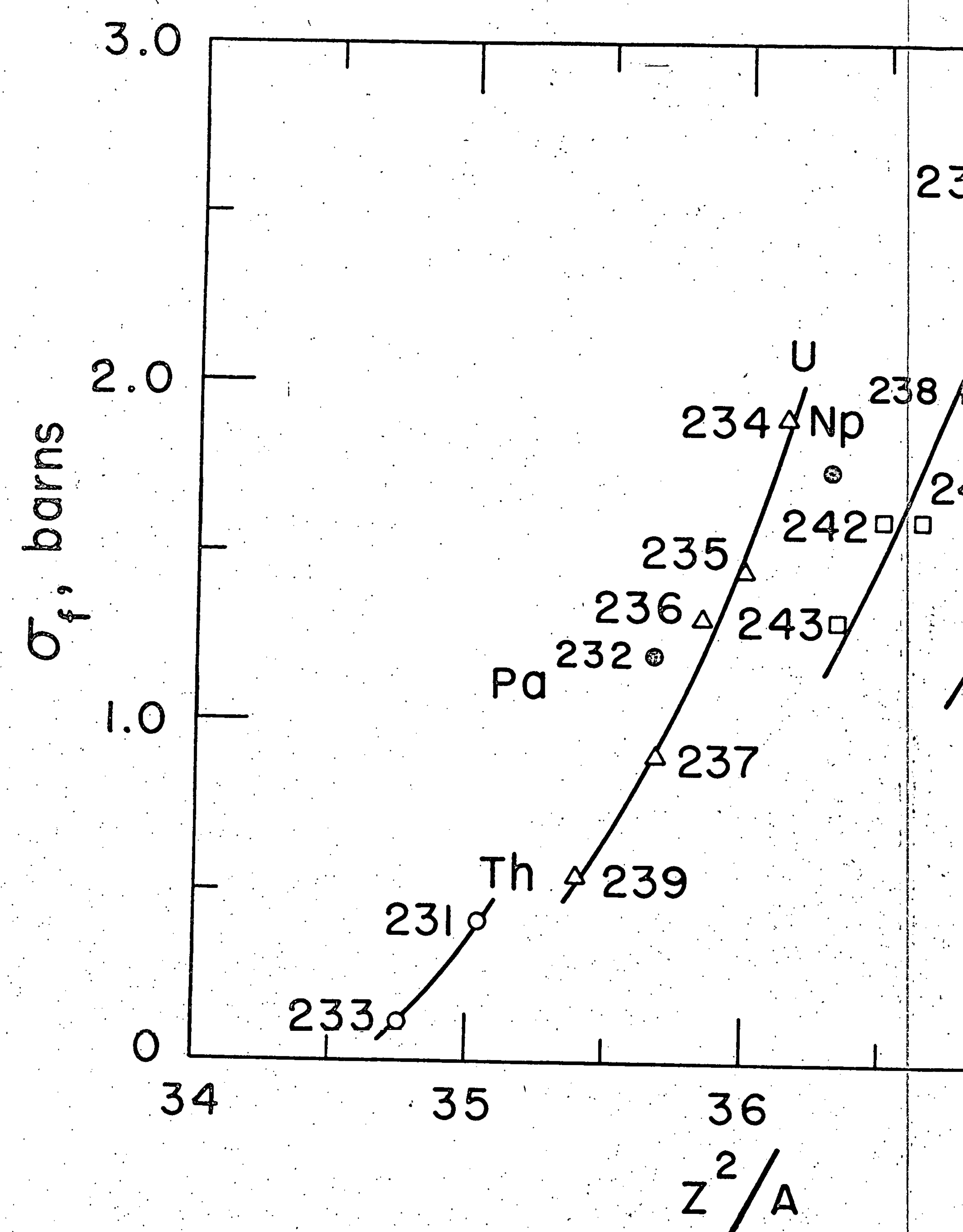


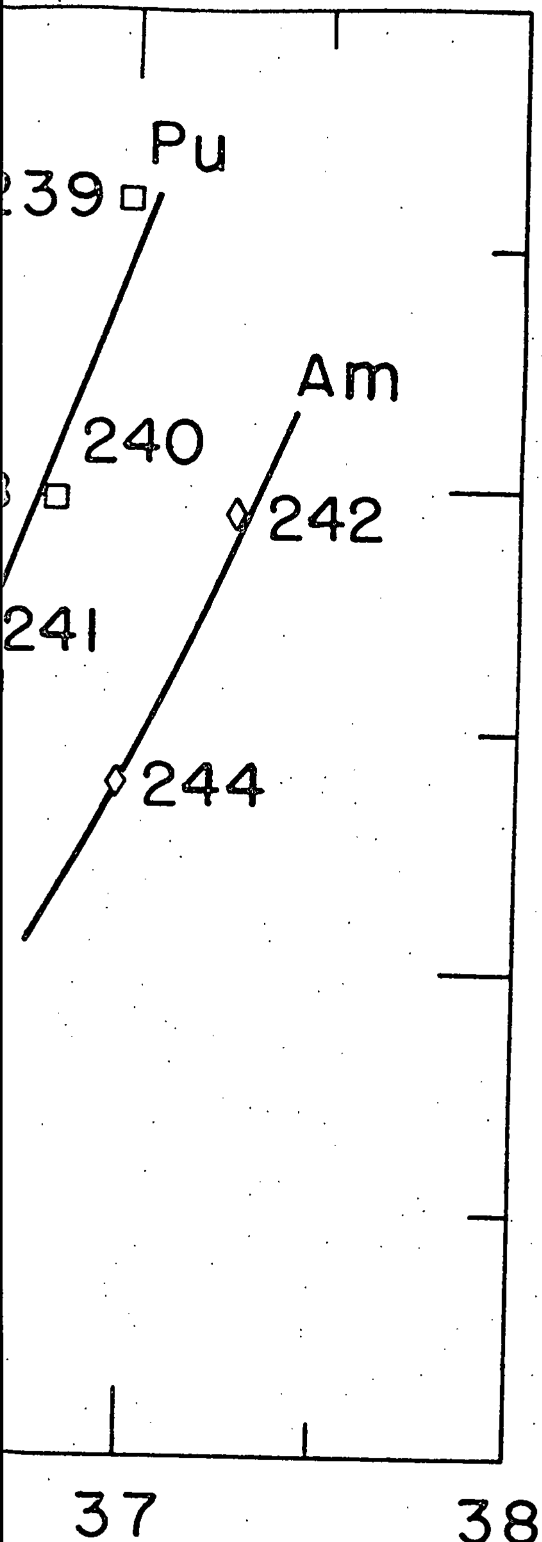
FIG. I

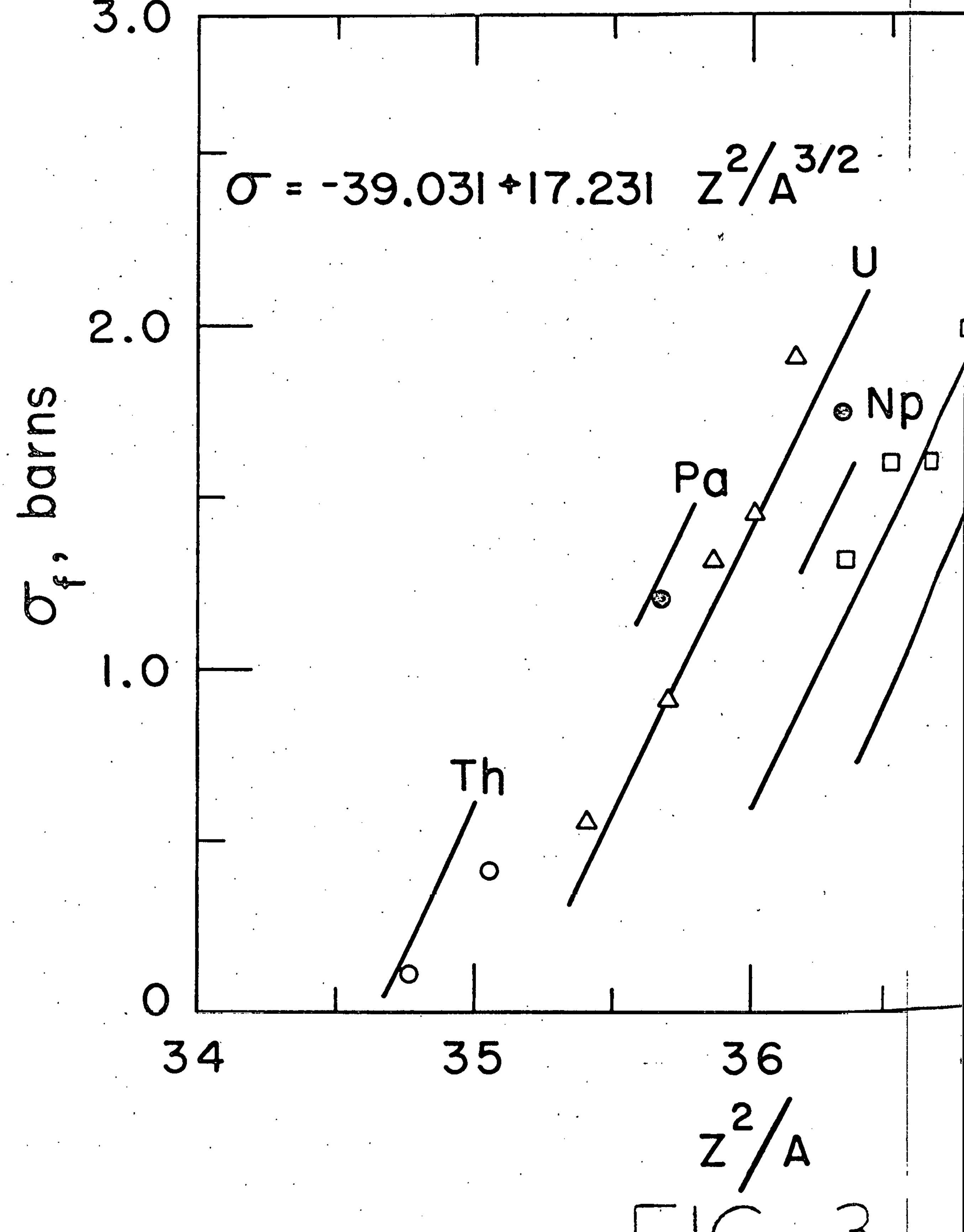

1.5



3.0
2.0
1.0
0
σ_f, barns
34
35
36
Z^2/A
U
234
Np
238
235
236
243
242
Pa
232
237
Th
239
231
233

FIG.2


Pu
239
240
241
Am
242
244
37
38



3.0
2.0
1.0
0
$\sigma = -39.031 + 17.231\ Z^2/A^{3/2}$
U
Np
Pa
Th
σ_f, barns
34
35
36
Z^2/A

FIG. 3

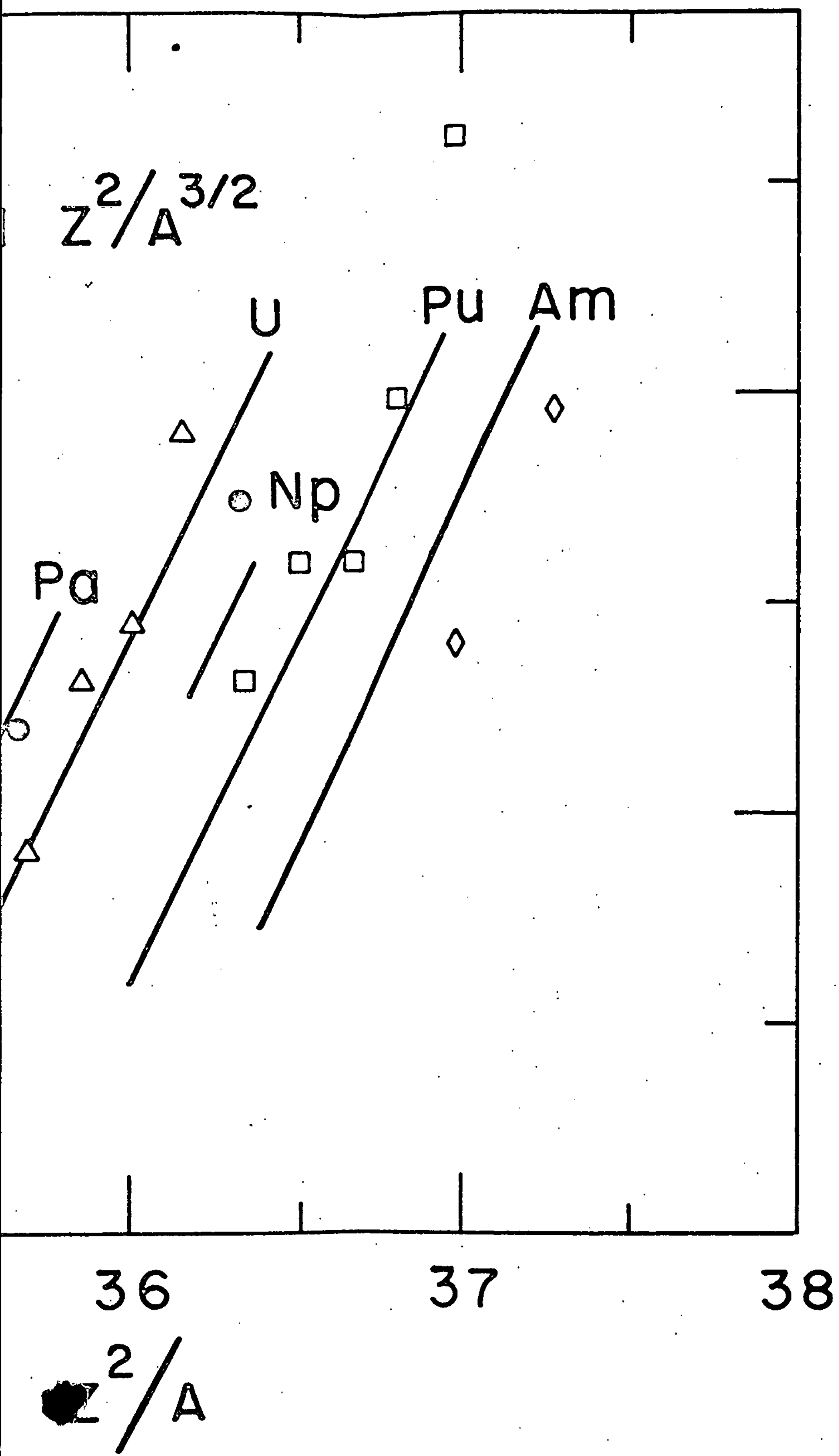


FIG. 3