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ABSTRACT

An evaluation of the smooth neutron total cross section for tungsten between 0.02 and 22 MeV is presented. It is argued that present evidence does not warrant separate treatment for the isotopes except for fluctuations and below 0.7 MeV.

I. INTRODUCTION

This paper is an interim report in the evaluation of tungsten neutron cross sections and gives the smooth total cross section from 0.02 to 22 MeV. An evaluation is clearly most reliable if solidly founded on experiment or upon an experimentally verified theory. Accordingly we have taken the hard line that expected but unsubstantiated features of the cross section should not be included. We hope thereby to avoid the common evaluation error of misleading the user with insignificant detail, and incidentally to reduce unnecessary information transmission and storage.

In that connection, the available experimental and theoretical knowledge simply will not support an evaluation of the separated isotopes which is significantly different from that for normal tungsten. Two exceptions occur: fluctuations, which we discuss below, and the cross sections below 0.7 MeV. In the latter case, we find that the Whalen and Meadows data (Wh66) show a significant difference between even and odd isotopes.

We have weighted experiment according to the stated error, point scatter, comparisons with other data, age, consistency, extensiveness, and general theoretical expectations. Consequently we have relied heavily on the work of Whalen and Meadows (Wh66) and Foster and Glasgow (Fo71). These authors quoted the lowest errors, had the lowest point scatter, and generally agreed with others or obtained a middle position compared to others. Also, their work was recent, consistent, and extensive, showing the generally expected behavior of Peterson-Ramsauer giant resonances (Gl71, Pe62, McV65, McV67, McV68).

II. RESULTS

We present the smooth total cross sections in a series of graphs, (Figs. 1 - 6 at the end of this report), together with experimental points. When many experimental points are given, we have put error bars on only a few representative points, and not at all on some older data, for clarity. References to experiment are given on each graph.

The smooth curve through the data was generated by fitting quadratic polynomials to sections of the data ranging up to 35 consecutive points. Since there are no reliable measurements at 2.0 MeV, we have used the systematics of the giant-resonance structure to estimate the position of the maximum cross section, making use of the simple theory of Peterson (Pe62) and the data of Foster and Glasgow (Fo71). The result is in general agreement with the local optical-model calculations of Agee and Rosen (Ag66) and the nonlocal optical-model calculations of Glasgow and Foster (Gl71).

For natural tungsten from 0.02 to 22 MeV, read the curves of Figs. 1 through 5 to obtain the smooth cross section, σ_T. For ^{183}W smooth σ_T, take the top curve of Fig. 6 from 0.1 to 0.5 MeV, then join linearly (or smoothly, as preferred; differences are now within experimental error) on to Fig. 2 over 0.5 to 0.7 MeV and use tungsten Figs. 2 to 5 from 0.7 to 22 MeV. For W-even isotopes (180, 182, 184, 186), use the lower curve of Fig. 6 from 0.1 to 0.5 then join linearly on to Fig. 2 over 0.5 to 0.7 MeV and use tungsten Figs. 2 to 5 from 0.7 to 22 MeV.

We do not offer isotopic σ_T below 0.1 MeV at this time. For a preliminary assessment of fluctuations, see below.

III. DISCUSSION

A. Isotopic Differences

The isotopic abundances used are (Ni58):

^{180}W	0.135%
^{182}W	26.41%
^{183}W	14.40%
^{184}W	30.64%
^{186}W	28.41%

We took the total cross section of ^{180}W to be the same as that of ^{182}W with a combined abundance of 26.55%. The atomic weight of natural tungsten is 183.85.

We find that the data above 0.7 MeV will not support isotopic total cross sections significantly different from those of natural tungsten. Slight differences, but within experimental error, do occur. No theory known to us, and certainly no experimentally verified theory, is ready to advise us except in the most general and average way. Moreover, we note that Glasgow and Foster (Gl71) argue that ^{182}W is a $1h_{11/2}$ deformed, and ^{186}W a $1h_{11/2}$ transition, nucleus (~ spherical) so that general theories would be inaccurate in giving the variations over the tungsten isotopes. We list the principal evidence supporting this position below.

1. No ^{183}W data. The older data of Selove (Se51) are rejected as being now too crude. For example, for ^{182}W he finds σ_T = 11.6 b at 0.2 MeV; we find (Fig. 6) 7.33 b. At 0.5 MeV he finds σ_T = 0.9 b, whereas we have σ_T = 6.58 b. The differences are similar for the other isotopes.
2. Except for the Whalen and Meadows (Wh66) data below 0.66 MeV, no simultaneous data of W and ^{182}W, ^{184}W, and ^{186}W exist. It is especially regrettable that samples of ^{183}W and ^{184}W could not be obtained for the encyclopedic measurements of Foster and Glasgow (Fo71).
3. Over large energy regions, the isotopic cross sections are represented by a single author's data with large error, large point spread (as great as 2 out of 7 barns), and significant discrepancy with other authors where overlapping data do exist.

In the single instance of the data of Whalen and Meadows from 0.1 to 0.65 MeV, we believe that the cross sections of the even isotopes are significantly below those of natural tungsten. We have subtracted the sum of the even isotopes times their abundances from natural tungsten and divided by the ^{183}W abundance to obtain $\sigma_T(^{183}W)$ which is the upper curve of Fig. 6. The lower curve is the relative-abundance-weighted average of the even isotopes and is intended to be used for σ_T of any even isotope. In Fig. 6 the point scatter exceeds the indicated experimental error by about 50%; consequently, the difference between the two curves above 0.4 MeV cannot be regarded as significant.

B. Fluctuations

The recent highly detailed measurements (Ma67, Wh66, Fo71, Sm64) of the total cross sections of the tungsten isotopes give some evidence for the presence of fluctuations, indeed as much as 2.5 barns out of 7 barns (Ma67). The sliding-polynomial fits used to smooth the data for Figs. 1 - 6, when studied as a function of the length of the smoothing interval, give clear evidence for intermediate structure outside of the quoted statistics in the data of Whalen and Meadows below 0.6 MeV. The same technique yields weaker evidence for fluctuations in the data of Martin, and marginal evidence in the data of Foster and Glasgow. Unfortunately, detailed comparison fails to show any consistent correlation in the apparent structure displayed in the latter two experiments, and they offer no overlap with the data of Whalen and Meadows. Similarly, the fluctuations observed by Whalen and Meadows for the isotopes of tungsten do not correlate well with their observed fluctuations in natural tungsten. Accordingly, for the present we have omitted the fluctuations from this evaluation.

It may be expected that experimental technique of comparable resolution and precision to that of the Karlsruhe group (Ci68) will exhibit fluctuations in heavy nuclei near MeV energies, even further from magic numbers than their measured thallium and bismuth. Certainly one expects fluctuations on theoretical grounds by reason of the following arguments: by averaging level densities obtained from experiment (Gdm66, Ba69) and using an average energy dependence of the density (Er61,Ts66,Bo69,Gi165; binding energy of the last neutron from Ma65), together with relative penetrabilities of the different partial waves (c.f. B152) and inelastic scattering thresholds (Wa66,Ar66,Ma66,Gov66), applied to neutron widths plus gamma widths (both Ba69,Gol66), suitably Doppler-broadened for 300°K tungsten temperature ((15a) of De65), we find that the compound-nuclear resonances in the even isotopes are still isolated up to about 0.4-0.5 MeV and that those in ^{183}W are isolated to about 0.1 MeV. So the violent structure of isolated resonances is expected theoretically at the low-energy end of our range, as well as doorway states (c.f. Fe67) and statistical fluctuations of which Ericson fluctuations (Er60, Er63,Br63,Gib65,Mo64,Ma70) are an expected type at the high-energy limit of our range. Thus the absence of fluctuations in our smooth cross sections is artificial and represents a lack of evidence, not a lack of variation. Consequently, users of the cross sections would be well advised to test the sensitivity of their cross-section use by the introduction of artificial variation about the mean, until such time as further experimental and theoretical study permits evaluators to describe the fluctuations that are certain to exist, but are not yet demonstrable, except possibly by correlation technique (Gib65, Ma70), not attempted here. We do note that the amplitude of the fluctuation in normal tungsten will be roughly one-half that of the individual isotopes.

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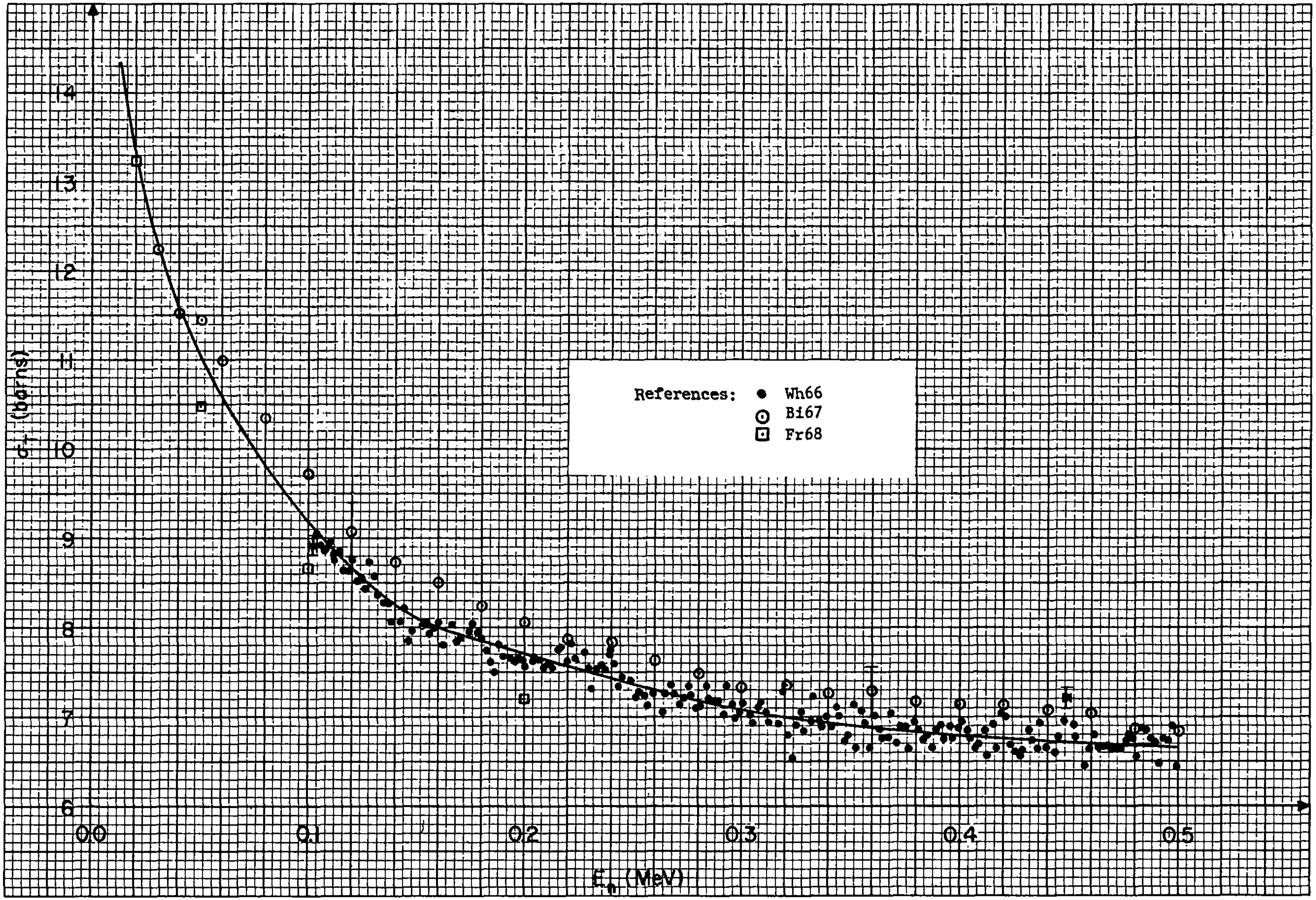

Fig. 1 Tungsten Smooth Total Cross Section

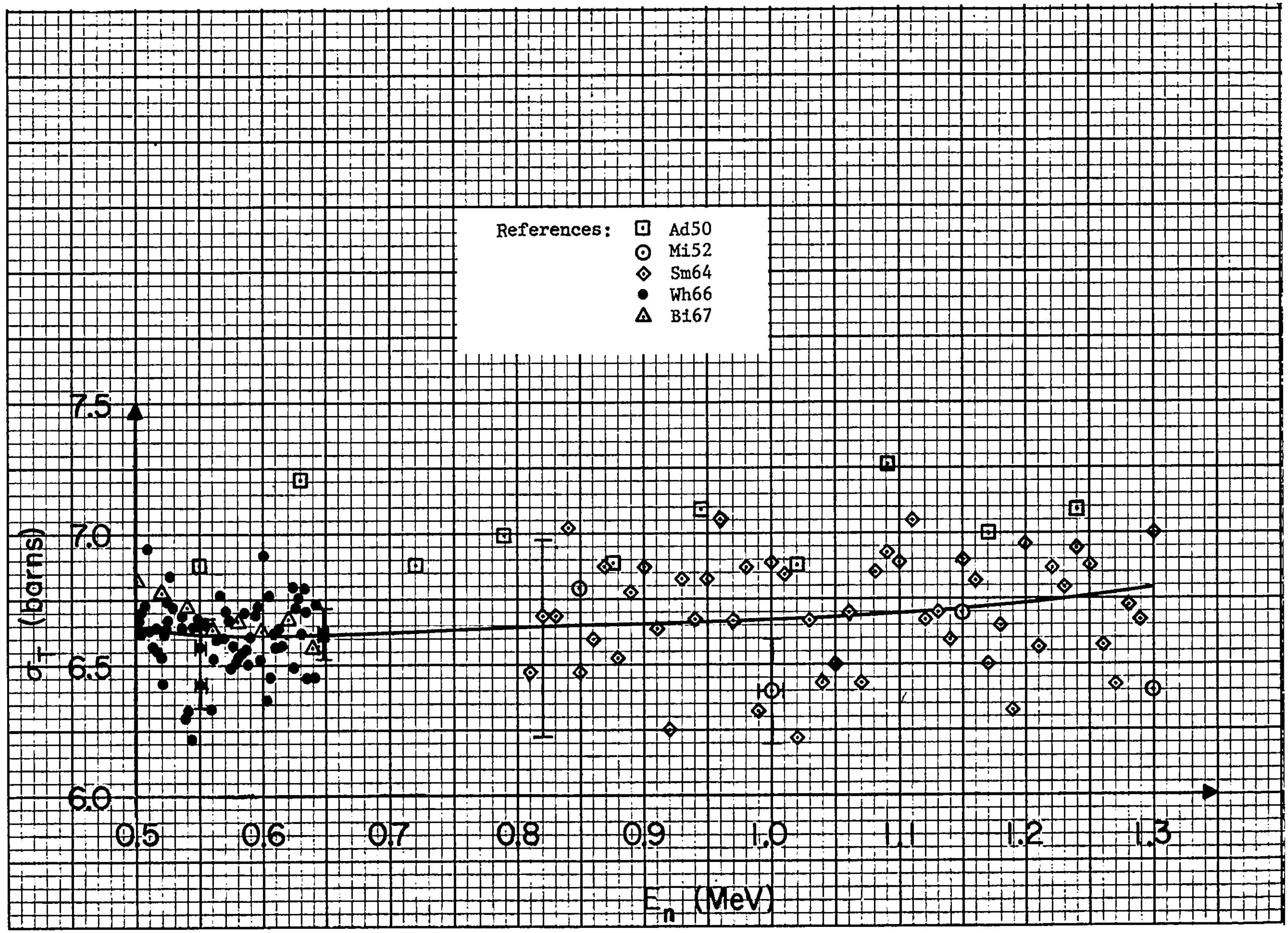

Fig. 2 Tungsten Smooth Total Cross Section

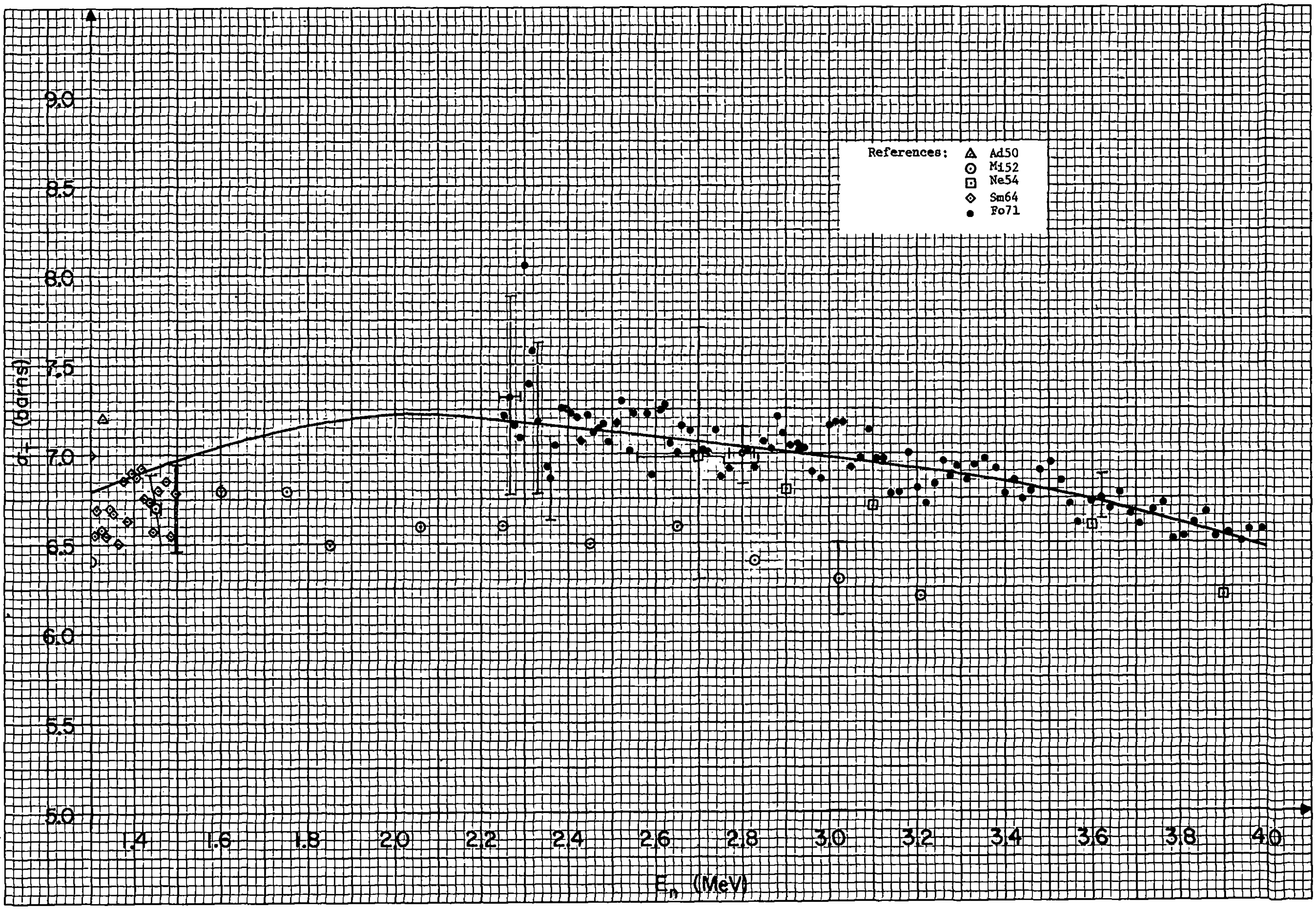

Fig. 3 Tungsten Smooth Total Cross Section

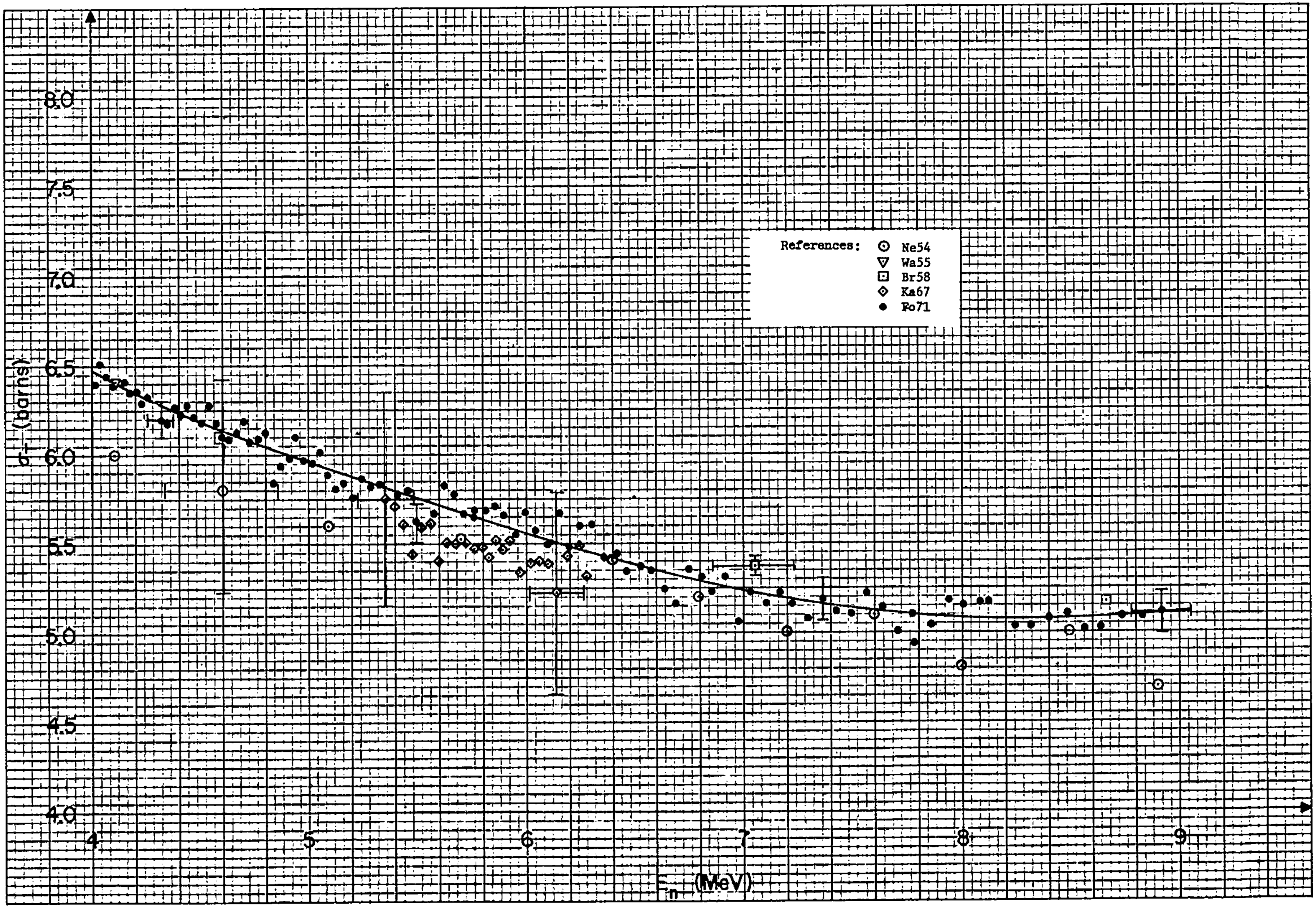

Fig. 4 Tungsten Smooth Total Cross Section

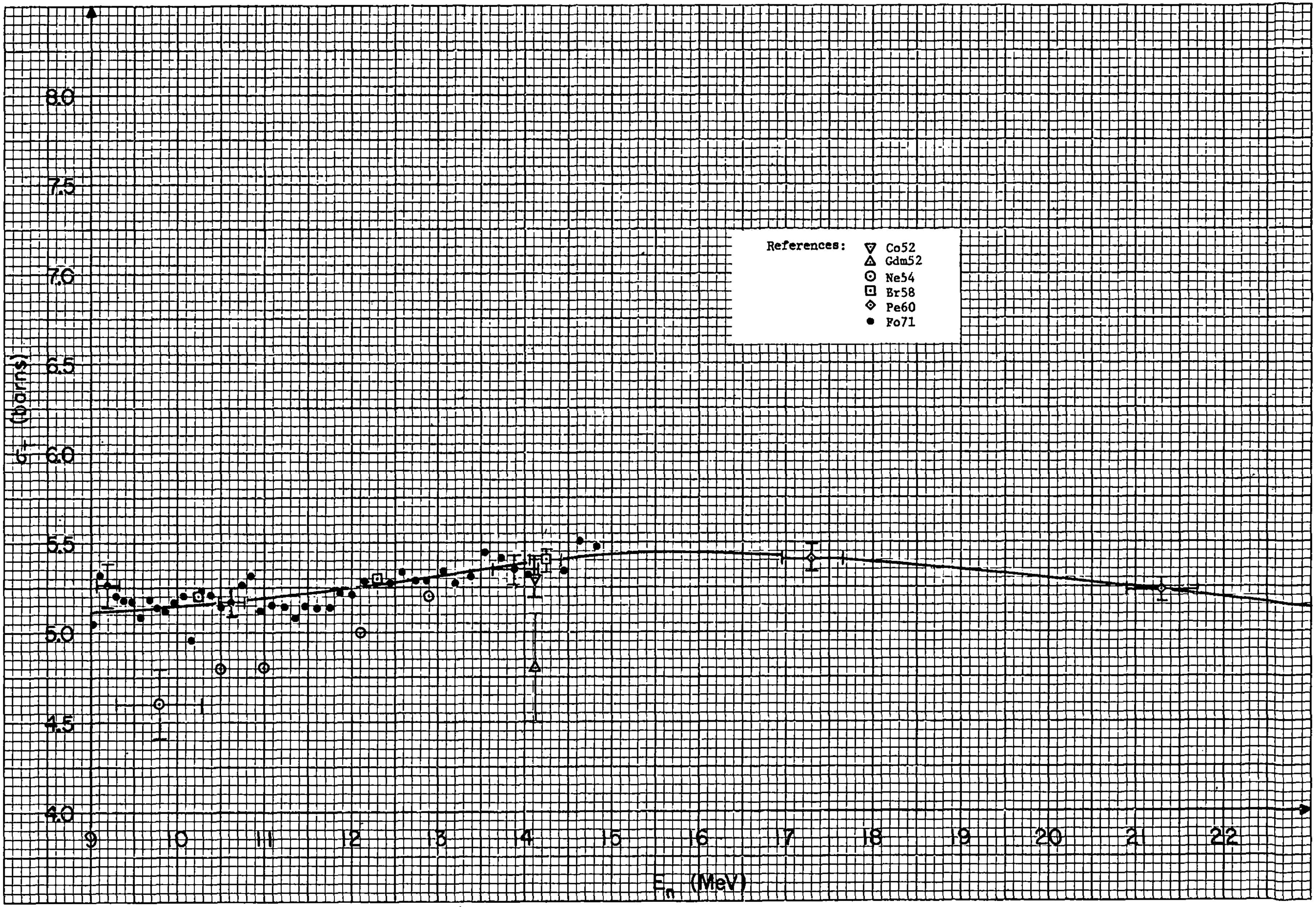

Fig. 5 Tungsten Smooth Total Cross Section

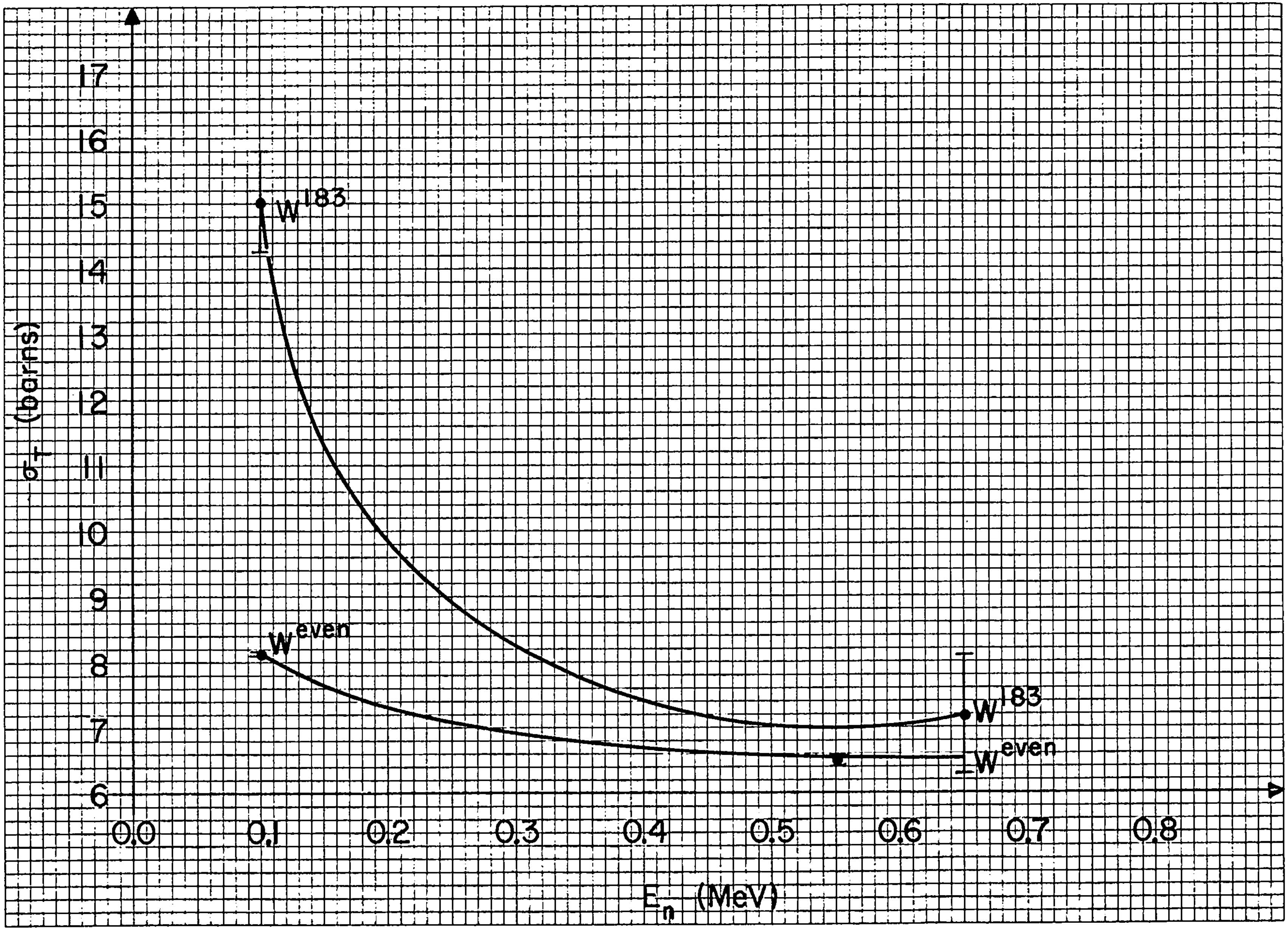

Fig. 6 Isotopic Tungsten Smooth Total Cross Section