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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Total Photon Absorption Cross Section Measurements, Theoretical Analysis and Evaluations for Energies Above 10 MeV

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FOREWORD

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The present report consists of tables of calculated atomic photoabsorption cross sections for energies above 10 MeV and a comparison with selected experimental results. This work was carried out as part of the program of the NSRDS X-Ray and Ionizing Radiation Data Center.

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TOTAL PHOTON ABSORPTION CROSS SECTION MEASUREMENTS, THEORETICAL ANALYSIS AND EVALUATIONS FOR ENERGIES ABOVE 10 MeV*

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Atomic photoabsorption cross sections have been calculated in the energy range from 10 MeV to 350 MeV. For Pb, Ta, Sn and Cu total γ-ray absorption cross sections were measured between 10 MeV and 160 MeV and compared with the theoretical results. An estimate of the uncertainties in the calculated atomic cross sections is given.

Key words: Coulomb corrections; pair production cross section; screening corrections; total photon absorption cross section; total photonuclear absorption cross section; triplet production cross section.

1. INTRODUCTION

In recent years total photon absorption cross sections, $\sigma_{tot}(k)$, have been measured with an accuracy of a few tenths of a percent for light elements (Li, Be, C, O, Aℓ, Ca) at photon energies k ranging from 10 MeV to between 150 and 220 MeV [1][1]. The aim of these measurements was to obtain nuclear absorption cross sections, $\sigma_{nucl}(k)$, for γ-radiation which are the difference between the total absorption cross sections, $\sigma_{tot}(k)$, and the nonnuclear or atomic cross sections, $\sigma_a(k)$, resulting from the electromagnetic reactions of the photons with the atom:

$$\sigma_{nucl}(k) = \sigma_{tot}(k) - \sigma_a(k) \quad . \tag{1}$$

Unfortunately, the nuclear absorption cross sections constitute only a small fraction -- at most 5-7% -- of the total absorption cross section. This means that in order to extract the nuclear absorption cross section from the measured total absorption cross section, it is essential to know the atomic cross sections as accurately as possible. Figure 1 depicts this situation very clearly.

Besides this nuclear physics aspect it would be desirable to have precise photon absorption cross sections in fields like radiation shielding analysis and medical dosimetry.

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*Report written at the National Bureau of Standards under a contract from the NBS Office of Standard Reference Data.

[1]Figures in brackets indicate the literature references at the end of this paper.

In section 3 of this paper, an attempt is made to compute the atomic cross sections for γ-radiation on the basis of most recent theoretical evaluations. These results are compared with earlier computations reported in literature. Section 4 describes total absorption measurements performed on high Z elements (Cu, Sn, Ta, Pb), where the nuclear part of the total cross section is known from (γ,n)-experiments. Therefore, in this case the experimental total absorption cross sections can be used to check the computed atomic cross sections. Section 5, finally, compares all experimental values with the theoretical atomic cross sections and gives an estimated accuracy of these calculations.

2. NOTATION, CONSTANTS

k	photon energy in units of the electron rest-mass energy m_oc^2
E	photon energy in MeV
Z	atomic number
σ_{tot}	total absorption cross section for γ-radiation
σ_{nucl}	nuclear absorption cross section for γ-radiation
σ_a	atomic (or electronic) photoabsorption cross section
σ_{ph}	cross section for the atomic photoeffect
σ_c	cross section for Compton effect
σ_t	cross section for pair production in the electron field (triplet production)
σ_p	cross section for pair production in the nuclear Coulomb field
ΔS	screening correction for pair production in the nuclear field
ΔS_t	screening correction for triplet production
ΔCoul	Coulomb correction for pair production in the nuclear field
f_{rad}	radiative correction
f_{ret}	retardation correction
ψ_o	atomic ground state wave function
q	momentum transfer to an atom or electron in m_oc units
$F(q,Z)$	atomic form factor, $F(0,Z) = Z$
$S(q,Z)$	inelastic (or incoherent) scattering function, $S(\infty,Z) = Z$
r_o	classical electron radius $= 2.81777 \times 10^{-13}$ cm
α	fine structure constant $= 7.2972 \times 10^{-3}$
m_oc^2	electron rest-mass energy $= 0.511006$ MeV
c_f	conversion factor for momentum transfer: $q\ [\text{Å}^{-1}] = 20.60821\ q'\ [m_oc]$

All cross sections are given in mbarns (mb).

3. ATOMIC PHOTOABSORPTION CROSS SECTIONS

The atomic cross sections for γ-ray absorption at energies above 10 MeV can be written as the sum of the partial cross sections for the photoelectric effect, σ_{ph}, for Compton effect, σ_c, for pair production in the Coulomb field of the nucleus, σ_p, and for pair production in the electron field of the atom (triplet production), σ_t:

$$\sigma_a = \sigma_{ph} + \sigma_c + \sigma_p + \sigma_t \tag{2}$$

Figures 2-4 show the energy dependence of these partial cross sections for lithium, calcium and lead. Table I gives the numerical values for the atomic photoabsorption cross sections and for the partial cross sections evaluated in this paper.

Report NSRDS-NBS 29 [2] reviews all theoretical and experimental results concerning the atomic cross sections up to 1969.

In the following paragraphs the methods used to compute the partial atomic cross sections are outlined and compared with previous calculations.

3.1. Photoelectric Cross Section

The photoelectric cross sections of this paper (table I) were computed by using an empirical formula given in Ref. [2]:

$$\sigma_{ph} = Z^5 f \sum_{i=1}^{4} \frac{a_i + b_i Z}{1 + c_i Z} E^{-p_i} \tag{3}$$

with

$$f = 1 + 0.01481 \ln^2 Z - 0.000788 \ln^3 Z \tag{4}$$

and

i	a_i	b_i	c_i	p_i
1	1.6268×10^{-6}	-2.683×10^{-9}	4.173×10^{-2}	1
2	1.5274×10^{-6}	-5.110×10^{-10}	1.027×10^{-2}	2
3	1.1330×10^{-6}	-2.177×10^{-9}	2.013×10^{-2}	3.5
4	-9.12×10^{-8}	0	0	4

This formula is estimated to be accurate within approximately 5%. But since the photoelectric effect is only important for high Z elements and low energies (table I), this results in an uncertainty of less than 0.05% of the total cross section for lead at 10 MeV.

3.2. Compton Cross Section

Hubbell et al [3] have calculated bound-electron Compton cross sections by applying incoherent scattering functions to the Klein-Nishina formula. However, it turns out that the binding effect can be neglected at energies above 10 MeV since for these energies it is smaller than 0.04% of the Compton cross section. Therefore the Compton cross sections have been computed by using the Klein-Nishina formula [4]:

$$\sigma_c = 2\pi\, r_o^{\,2} \left[\frac{1+k}{k^2}\left(\frac{2(1+k)}{1+2k} - \frac{\ell n(1+2k)}{k}\right) + \frac{\ell n(1+2k)}{2k} - \frac{1+3k}{(1+2k)^2}\right] \tag{5}$$

Radiative and double Compton effect corrections of 0.3 to 1.3% of the Compton cross section evaluated by Mork [5] and tabulated in [2] have been added to the results of formula (5). Table I gives the final Compton cross sections in column 4.

The Compton cross section is an essential fraction of the total absorption cross section at small energies (see figs. 2-4). But fortunately it decreases rapidly with energy. Therefore, the corrections of the Compton cross section are less than 0.3% of the total cross section in the energy region and for the elements considered in this paper. The uncertainty of the total absorption cross section arising from the uncertainty of the Compton cross section is estimated to be less than 0.1%, and even smaller for high energies and heavy elements.

3.3. Pair Production in the Coulomb Field of the Nucleus

The pair production cross section is the most important part of the atomic absorption cross section, especially for high Z elements (figs. 2-4). For lead e.g., it constitutes about 74% of the total cross section at 10 MeV and about 97% at 150 MeV, but even for a light element such as lithium it is 43% at 50 MeV and 64% at 200 MeV. Therefore most of the efforts were concentrated on the evaluation of precise pair production cross sections.

Bethe and Heitler have calculated the pair production cross section in the nuclear Coulomb field in a plane wave approximation [6]. For high Z elements however, this approximation is not appropriate, and therefore a "Coulomb correction" has to be applied which takes into account that the outgoing leptons can no longer be represented by plane waves. A second important effect is the screening of the nuclear Coulomb field by the surrounding atomic electron cloud. The Z and energy dependence of both effects is shown in figure 5 which illustrates the importance of the Coulomb and the screening corrections. For lead at 150 MeV e.g., they constitute 11% and 27% resp. of the total cross section. A third correction has to be applied to account for radiative effects.

In this analysis the pair production cross section, σ_p, is written as:

$$\sigma_p = (\sigma_{BH} - \Delta S - \Delta\mathrm{Coul})\, f_{rad} \tag{6}$$

where σ_{BH} is the unscreened plane wave approximation of Bethe and Heitler, ΔS the screening correction, $\Delta\mathrm{Coul}$ the Coulomb correction and f_{rad} the radiative correction.

The formulation of the pair production cross section in terms of formula (6) is not obvious because screening, Coulomb and radiative corrections are not independent of each other. Reference [7] justifies separating the screening and the Coulomb correction by the argument that screening is mainly related to small momentum transfers in the pair production process whilst the Coulomb correction is due to large momentum transfers or small impact parameters. It is, however, not quite clear what error is introduced by splitting the two corrections into separate terms. A rough estimate based on the mentioned momentum transfer considerations results in an uncertainty of less than 0.1% of the total absorption cross section [8]. This 0.1% uncertainty contribution has been independently estimated by Øverbø [9], assuming the worst case of a heavy element where $F(q,Z) \approx 0.01$ for $q \approx 1$ mc, resulting in a few tenths of a percent screening correction to the Coulomb correction, applied to a Coulomb correction of as much as 10%.

The main part of formula (6), the unscreened pair production cross section, σ_{BH}, was computed using Maximon's expansion [10]:

$$\sigma_{BH} = Z^2 \alpha r_o^2 \left[\frac{28}{9} \ln 2k - \frac{218}{27} + \left(\frac{2}{k}\right)^2 \left(6 \ln 2k - 3.5 + \frac{2}{3} \ln^3 2k - \ln^2 2k - \frac{1}{3} \pi^2 \ln 2k + 2 \zeta(3) + \frac{\pi^2}{6}\right)\right.$$
$$- \left(\frac{2}{k}\right)^4 \left(\frac{3}{16} \ln 2k + \frac{1}{8}\right)$$
$$\left. - \left(\frac{2}{k}\right)^6 \left(\frac{29}{2304} \ln 2k - \frac{77}{13824}\right) + \ldots\right] \tag{7}$$

with $\zeta(3) = \sum_{n=1}^{\infty} \frac{1}{n^3} = 1.2020569$ (Riemann's Zeta function).

The radiative correction, f_{rad}, was taken from reference [11] and is given by:

$$f_{rad} = 1 + 0.0093 \frac{\ln 2k - 1.58}{\ln 2k - 2.08} \tag{8}$$

According to reference [11] the uncertainty of the radiative correction caused by applying or not applying the screening effect is negligible (less than 0.05% of the total absorption cross section).

Very recently, Øverbø evaluated the Coulomb correction cross section [12] combining his former low energy (up to 5 MeV) results [13] with the high energy approximation of Davies, Bethe and Maximon (DBM) [7] (fig. 6):

$$\Delta\text{Coul} = Z^2 \alpha r_o^2 \left[4 f(Z)\left(\frac{7}{9} - \frac{2}{k} + \frac{4}{3k^2} - \frac{8}{9k^3}\right) - g(k,Z)\right] \tag{9}$$

with

$$f(Z) = a^2 \left(\frac{1}{1+a^2} + 0.20206 - 0.0369a^2 + 0.0083a^4 - 0.002a^6 + \ldots\right) , \tag{10}$$

$$a = \alpha Z , \tag{11}$$

$$g(k,Z) = \frac{1}{k} \left[c_1 \ln^2 \frac{k}{2} + c_2 \ln \frac{k}{2} + c_3\left(1 - \frac{2}{k}\right)\right] + \frac{1}{k^2} \left[c_4 \ln^3 \frac{k}{2} + c_5 \ln^2 \frac{k}{2} + c_6 \left(1 - \frac{2}{k}\right)\right] , \tag{12}$$

$$c_1 = a^2 \ (-6.366 + 4.14a^2) \quad , \tag{13}$$

$$c_2 = a^2 \ (54.039 - 43.126a^2 + 11.264a^4) \quad , \tag{14}$$

$$c_3 = a^2 \ (-52.423 + 49.615a^2 - 14.082a^4) \quad , \tag{15}$$

$$c_4 = 10.938a^2 \ (1 - 3.086a^2) \quad , \tag{16}$$

$$c_5 = - \ 12.705a^2 \ (1 - 3.086a^2) \quad , \tag{17}$$

$$c_6 = 9.093a^2 \ (1 - 3.086a^2) \quad . \tag{18}$$

The energy and Z dependence of the Coulomb correction term computed from formula (9) is shown in figure 5 as percentage of the total absorption cross section. Errors in the above Coulomb correction fit (equations (9)-(18)) are estimated by Øverbø [12] to be of the order of 0.1% of σ_{BH}.

The screening correction ΔS can be calculated by applying the atomic form factor

$$F(q,Z) = \sum_{n=1}^{Z} \langle \psi_o \mid e^{iqr_n} \mid \psi_o \rangle \tag{19}$$

(q = recoil momentum, ψ_o = ground state wave function, r_n electron coordinate) to the unscreened recoil distribution $\frac{d\sigma}{dq}$ (k,q) of the nucleus:

$$\Delta S = \int_{q_o}^{q_1} \frac{d\sigma}{dq} \ (k,q) \left[1 - \left(1 - \frac{F(q,Z)}{Z}\right)^2\right] dq \quad . \tag{20}$$

The recoil distribution used in this report was derived by Jost, Luttinger and Slotnick [14]. It is reported throughout the literature with various misprints; the correct formula (without the screening factor $\left[1 - \frac{F(q,Z)}{Z}\right]^2$) is:

$$\frac{d\sigma}{dq} = \frac{8\alpha Z^2 r_o^{\,2}}{k^2 q^3} \ I(q,k) \quad , \tag{21}$$

$$I(q,k) = \left(1 - \frac{1}{2}\,q^2\right) J_1 + \left(1 - q^2 - 2qk + \frac{q^4-4}{3qk}\right) \ln\,(\sqrt{y} + \sqrt{y-1}) + \left(3 + \frac{2k}{3q} + \frac{2q^2-4}{3qk}\right) \sqrt{y(y-1)}$$

$$+ \frac{1}{\sqrt{1+4/q^2}} \left[-\frac{1}{2}\,(4 + q^2) + \frac{2k^2}{3} \left(\frac{1}{q^2} - 1\right)\right] \ln \frac{\sqrt{1+4/q^2} - \sqrt{1-1/y}}{\sqrt{1+4/q^2} + \sqrt{1-1/y}} \tag{22}$$

with

$$y = \frac{1}{4}\,(2qk - q^2) \quad , \tag{23}$$

$$J_1 = L_2(-x_1) + L_2(-x_2) + \frac{1}{2}\,\ln^2\lambda + (\ln v) \left(\frac{1}{2}\,\ln v - \ln 2qk\right) + \frac{\pi^2}{6} \quad , \tag{24}$$

$$x_1 = \frac{1}{v\lambda} \quad , \quad x_2 = \frac{\lambda}{v} \quad , \tag{25}$$

$$\lambda = \frac{1}{4}\left(q + \sqrt{q^2+4}\right)^2 \quad , \tag{26}$$

$$v = \left(\sqrt{y-1} + \sqrt{y}\right)^2 \quad . \tag{27}$$

L_2 is the Spence function or dilogarithm [15] defined by:

$$L_2(-x) = -\int_o^{-x} \frac{\ell n(1-t)}{t}\, dt \tag{28}$$

$L_2(-x)$ can be expanded

$$L_2(-x) = -\sum_{i=1}^{\infty} \frac{(-x)^i}{i^2} \quad \text{for} \quad |\, x\, | \leq 1 \tag{29}$$

Another useful relation is:

$$L_2(-x) = L_2\left(\frac{1}{1+x}\right) - \frac{1}{2}\,\ell n\,(1+x)\,\ell n\left(\frac{x^2}{1+x}\right) - \frac{\pi^2}{6} \quad \text{for} \quad x > 0 \tag{30}$$

In the present calculation formula (29) was used for $|x| < 0.6$ and formula (30) for the other values.

The limits of the integral in formula (20) are given by the minimum and maximum recoil momenta:

$$q_o = k - \sqrt{k^2-4} \leq q \leq k + \sqrt{k^2-4} = q_1 \tag{31}$$

Figure 7 shows the recoil distribution of formula (21) for various photon energies.

In previous papers [16,17] the atomic form factors, $F(q)$, used were either derived from the Thomas-Fermi model or based on nonrelativistic Hartree-Fock calculations. Recently, atomic form factors have become available which are calculated from relativistic charge densities obtained by the Hartree-Fock selfconsistent field method [18,19]. Since the recently measured total-absorption cross sections reported in [1] and [32] are of sufficient precision to distinguish between pair-production cross sections calculated using these different atomic models, it is possible here to show quantitatively the importance of using the latter relativistic $F(q)$ values, in preference to Thomas-Fermi or non-relativistic Hartree-Fock values, in computing theoretical estimates of the pair-production cross section.

In this paper three different sets of form factors are used:

a) form factors based on the Thomas-Fermi statistical model and described by the Molière approximation [20]:

$$F(q,Z) = 1 - q^2 \sum_{i=1}^{3} \frac{a_i}{c_i^{\,2}+q^2} \tag{32}$$

with $c_i = b_i Z^{1/3}/121$ and

$a_1 = 0.1, \quad a_2 = 0.55, \quad a_3 = 0.35,$

$b_1 = 6.0, \quad b_2 = 1.2, \quad b_3 = 0.3,$

b) nonrelativistic form factors extracted from reference [3] which were based on nonrelativistic Hartree-Fock calculations for small momentum transfers ($q \leq 10$ Å$^{-1} \approx 0.5\ m_o c$) and extrapolated for higher q values by the Bethe-Levinger relativistic K-shell formula [21],

c) relativistic form factors computed from atomic charge densities [18] by numerical Fourier transformation using Filon's integration method [22]. The charge densities were obtained from a self-consistent field program by Liberman et al [23]. These form factors were calculated independently by Øverbø [9] who used the same method, and they are found to be consistent within approximately 0.7% with those derived from Fricke's [18] charge densities.

The numerical integration of equation (20) was performed by using a Simpson integration routine with automatic step selection, integrating over two q regions ($q_1 \leq q \leq 1\ m_o c$ and $1\ m_o c \leq q \leq q_2$) and adding the two results. The integral over the small q-region contained the main part of the sum, since the integrand falls off very rapidly. As a check, the unscreened pair production cross section has been computed from the JLS recoil distribution:

$$\sigma_{unscr.}(k) = \int_{q_1}^{q_2} \frac{d\sigma}{dq}(q,k)\, dq \tag{33}$$

Comparing these results with the unscreened cross sections calculated from formula (7), no significant deviations were found within the accuracy of the numerical integration (10^{-6}). This agrees with Knasel's calculation of the unscreened pair production cross section [24] who also used the JLS formula. The consistency with formula (7) still holds in the energy region below 3 MeV where Knasel found deviations due to his approximation in evaluating the Spence function in the JLS recoil distribution (formulas (22), (24), (28-30)).

When integrating formula (20), the form factors of set b) and c), which were given in form of tables, were interpolated by a cubic spline function. A check was made by applying quadratic Lagrangian interpolation as well, resulting in no significant change of the screening correction values.

Table II gives the results of the screening correction computation for the three sets of form factors. Figure 5 shows the ratio of the screening correction (calculated with the relativistic form factors, set d) and the total absorption cross section.

The screening correction cross sections obtained with relativistic form factors agree within a few tenths of a percent with the values calculated by Øverbø [9]. For Li and Be the agreement is in the range of 1-2%. Compared with the total absorption cross section, this is, however, less than 0.1 percent.

In figure 8 the differences between the screening cross sections obtained with the relativistic (set c) rsp. the nonrelativistic (set b) form factors and those obtained with Thomas-Fermi form factors (set a) are plotted in units of the total atomic absorption cross section. The different behaviour of the curves for different elements reflects the shell structure of the atom which is not included in the Thomas-Fermi model but is included in the two other sets of form factors. Figure 8 also shows that the influence of relativistic effects is important for heavy elements.

3.4. Pair Production in the Field of the Atomic Electrons (Triplet Production)

The cross section for pair production in the field of the atomic electrons can be written in analogy to formula (6) for the pair production in the field of the nucleus as:

$$\sigma_t = (\sigma_o - \Delta S_t)\, f_{rad} \quad , \tag{34}$$

where σ_o is the unscreened triplet production cross section, ΔS_t the screening correction term for this process and f_{rad} the radiative correction factor. The Coulomb correction which is important for pair production in the nuclear field can be neglected for triplet production.

Borsellino and Ghizetti calculated the unscreened triplet cross section including retardation [25] which arises from the fact that the velocity of the recoiling electron is not negligible in comparison with the velocity of light. The formula they derived is given by the following expression:

$$\begin{aligned}\sigma_{BG}(k) = Z\,\alpha\, r_o^{\,2} \Bigg[& \frac{28}{9}\ln 2k - \frac{218}{27} \\ & + \frac{1}{k}\left(-\frac{4}{3}\ln^3 2k + 3\ln^2 2k - \frac{60+16a}{3}\ln 2k + \frac{123+12a+16b}{3}\right) \\ & + \frac{1}{k^2}\left(\frac{8}{3}\ln^3 2k - 4\ln^2 2k + \frac{51+32a}{3}\ln 2k - \frac{123+32a+64b}{6}\right) \\ & + \frac{1}{k^3}\left(\ln^2 2k - \frac{53}{9}\ln 2k - \frac{2915-288a}{216}\right) \\ & + \frac{1}{k^4}\left(-\frac{49}{18}\ln 2k - \frac{115}{432}\right) \\ & + \frac{1}{k^5}\left(-\frac{77}{36}\ln 2k + \frac{10831}{8640}\right) \\ & + \frac{1}{k^6}\left(-\frac{641}{300}\ln 2k + \frac{64573}{36000}\right) \\ & + \frac{1}{k^7}\left(-\frac{4423}{1800}\ln 2k + \frac{394979}{216000}\right) + \ldots \Bigg]\end{aligned} \tag{35}$$

with $a = -\,2.4674$ and $b = -\,1.8031$.

Recently Haug calculated the unscreened triplet cross section [26] including exchange terms arising from the indistinguishability of the two electrons involved in the triplet process and including the interaction between the incident photon and the initial electron. These two terms cancel partially and decrease with energy. They have been neglected in formula (35). However, a correction term, Δ, extracted from Haug's paper (Table III) has been applied to formula (35) in order to compute the unscreened cross section, σ_o:

$$\sigma_o = \sigma_{BG} + \Delta \tag{36}$$

The radiative correction factor of formula (34) has been derived by Mork and Olsen [11] and is almost independent of energy. In this paper a value of 1.01 was used.

The triplet screening correction, ΔS_o, was calculated in a similar manner as the screening for pair production in the nuclear field (formula (20)) thereby first neglecting retardation:

$$\Delta S_o = \int_{q_o}^{q_1} \frac{d\sigma}{dq}(q,k)\left(1 - \frac{S(q,Z)}{Z}\right) dq \tag{37}$$

$\frac{d\sigma}{dq}$ is the unscreened recoil distribution (formula (21) divided by Z) of Jost, Luttinger and Slotnick, $S(q,Z)$ is the incoherent scattering function as defined by [3]:

$$S(q,Z) = \sum_{m,n=1}^{Z} \left\langle \psi_o \right| e^{iq(r_m - r_n)} \left| \psi_o \right\rangle - \left| F(q,Z) \right|^2 \tag{38}$$

ψ_o is the ground state wave function of the atom and $F(q,Z)$ the atomic form factor. r_m and r_n are the space coordinates of the m^{th} and n^{th} electron.

The values for the incoherent scattering functions $S(q,Z)$ were taken from reference [3]. They are derived from nonrelativistic Hartree-Fock calculations; relativistic incoherent scattering functions are not available.

Since the JLS recoil distribution in formula (37) neglects the retardation effect in the triplet production process, the screening ΔS_o has to be corrected by a factor f_{ret}:

$$\Delta S_t = f_{ret}\, \Delta S_o \tag{39}$$

The cross section for pair production in the nuclear Coulomb field does not include retardation (formula (7)) whereas the cross section for triplet production does include this effect (formula (35)), the factor f_{ret} can be computed as the ratio of these unscreened cross sections for $Z = 1$:

$$f_{ret} = \sigma_o / \sigma_{BH} \tag{40}$$

Table IV and figure 9 show the energy dependence of the retardation factor. f_{ret} is considerably different from 1 for low energies. Fortunately the screening cross section itself is small in this region, therefore errors which might be introduced by the approximation in formula (39) are less severe.

The results of the triplet screening calculations are given in Table V. Figure 10 and 11 show the screening correction cross sections in units of the unscreened triplet cross section and of the total absorption cross section, resp. Although the triplet screening is a big effect as compared with the triplet cross section itself, it is only a fraction of less than 1.3% of the total cross section.

Hubbell has calculated screened triplet cross sections [2] in a high energy approximation using a method developed by Wheeler and Lamb [27] which neglects retardation. For high energies and without retardation, the screening corrections of this paper agree within 1% with those obtained by Hubbell. Knasel [24] applied a method similar to the one used in this work. He first calculated screened triplet cross sections for hydrogen and helium without retardation and thereafter added a term to correct the total triplet cross section for retardation instead of only correcting the screening values as described in this paper. But nevertheless there is good agreement between both results.

4. TOTAL ABSORPTION CROSS SECTION MEASUREMENTS

Total absorption cross sections for Li, Be, C, O, Aℓ, Si and Ca have been measured in the energy range of 10 MeV to energies beyond meson threshold in an earlier experiment [1] in order to obtain nuclear absorption cross sections. Measurements on heavy elements (Cu, Sn, Ta) were performed at certain energies between 10 and 160 MeV [32]. Lead was measured in the entire energy range from 10 to 160 MeV [32]. Figure 12 shows the experimental total absorption cross sections, the numerical values are given in table VI.

The total absorption cross sections were obtained in a narrow beam attenuation experiment using a bremsstrahlung beam with fixed end energy from the Mainz linear accelerator. The experimental set-up consisted mainly of two 11-channel magnetic Compton spectrometers with an energy resolution of 1% [28], one used as the main γ-spectrometer, the other used for normalization purposes. The cross sections, $\sigma_{tot}(k)$, were deduced from the number of registered photons in a certain energy bin with (N) and without (N_o) the absorption target in the photon beam by applying the absorption law:

$$N(k) = N_o(k)\, e^{-\frac{N_A \rho x}{A} \sigma_{tot}(k)} \tag{41}$$

with N_A = Avogadro's number, A = atomic weight of the absorbing material and ρx = density times length of the absorber.

The errors due to counting statistics are always indicated by error bars at the experimental values. All other types of errors or systematic uncertainties are discussed in detail in reference [1]. The uncertainties arising from the measurement of the absorber properties ρx are less than 0.1% for Cu, Sn, Ta and Pb. The overall systematic error is estimated to be less than 0.2% for all high Z elements.

5. DISCUSSION OF EXPERIMENTAL RESULTS AND THEORETICAL CALCULATIONS

The aim of the total absorption cross section measurements for high Z elements was to check the nonnuclear cross sections calculated in this paper rather than to perform a precise measurement of the nuclear cross section. Since the screening and the Coulomb correction terms for pair production in the electromagnetic field of the nucleus increase with the atomic number (see section 3.3) and the nuclear cross sections can be approximated very well by the (γ,n) cross section , absorption cross section measurements for high Z elements constitute a good test for the atomic cross sections, especially for the mentioned corrections.

In figure 13 the difference between the pair production screening corrections as they were calculated by applying relativistic and nonrelativistic form factors, is plotted in units of the total absorption cross section. For heavy elements, especially for lead, this difference is more than 1% of the total cross section. Therefore, it should be possible to test the calculated screening values with the experimental data. Assuming that the nuclear cross section is negligible above approximately 50 MeV and assuming that the partial atomic cross sections -- excluding the screening correction for pair production -- are known precisely from the calculations in section 3. an "experimental screening correction," ΔS_{exp}, can be evaluated according to formula (1), (2) and (6):

$$\sigma_{nucl} = \sigma_{tot} - \left(\sigma_{ph} + \sigma_c + \sigma_t + (\sigma_{BH} - \Delta S_{exp} - \Delta \mathrm{Coul})\, f_{rad}\right) \tag{42}$$

or with $\sigma_{nucl} = 0$ for high energies:

$$\Delta S_{exp} = \left(\sigma_{ph} + \sigma_c + \sigma_t + (\sigma_{BH} - \Delta \mathrm{Coul})\, f_{rad} - \sigma_{tot}\right) \Big/ f_{rad} \tag{43}$$

In figures 14-21 this experimental screening correction is plotted as well as the screening corrections calculated with relativistic and nonrelativistic form factors. For all measured high Z elements the relativistic form factors are favored compared with the nonrelativistic ones. Moreover, the deviations from the calculated values are within the uncertainties of the experimental cross sections. Therefore, the screening corrections obtained by using relativistic form factors are considered to be appropriate and are used in the following considerations as well as in table I of section 3.

The nuclear absorption cross sections for lead and tin are shown in figure 22 and 23. These cross sections were obtained by subtracting the calculated atomic cross sections from the measured total absorption cross sections without any adjustment or fitting procedures. The lines in figure 22 and 23 indicate the experimental (γ,n) cross sections computed from Lorentz line parameters given in reference [29]. In lead the deviations from zero for high energies are less than 0.4% of the total cross section and are not within the experimental uncertainty of 0.2%. Figure 24-27 display the giant resonance region of the nuclear absorption cross section for Pb, Ta, Sn and Cu. The curves in these plots again represent the (γ,n) cross sections. There is excellent agreement with the (γ,n) results for Pb, Ta and Sn.[2] For copper the total absorption cross section and the (γ,n) cross section differ by roughly 30%, but this discrepancy can easily be explained by the (γ,p) cross section which is of that order of magnitude [30,31] and has to be added to the (γ,n) cross sections to give the total cross section.

Figures 28-33 show the nuclear absorption cross section for γ-radiation in the elements Li, Be, C, O, Aℓ and Ca derived from the experimental data of a previous experiment [1] and the atomic cross sections calculated in this paper. Since for these elements the nuclear cross section is not known from other experiments, the only way of checking the atomic cross sections is to see if the resulting nuclear cross sections remain positive at all energies. This condition -- giving an upper limit for the atomic cross sections -- holds within the experimental uncertainties [1] for all elements investigated and for all energies.

6. CONCLUSION

Atomic cross sections for γ-ray absorption have been calculated in the energy range from 10 to 350 MeV using the most recent theoretical evaluations available. Comparing these results with the measured total absorption cross sections for high Z elements it was found that it is appropriate to use relativistic form factors to compute the screening correction term in the pair production cross section. On the basis of this approach, the calculated atomic cross sections are consistent with the experimental results for all energies covered by the experiment for low Z as well as for high Z elements.

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[2] The slight difference in the peak position might be due to an error in the energy calibration and needs further investigation.

The deviations of the calculated atomic cross section for lead at high energies from the experimental values is smaller than 0.4%. Since the main uncertainties for high Z elements arise from either the Coulomb or the screening correction which both decrease with decreasing atomic number, the uncertainty caused by these corrections in light elements should be considerably smaller. For low Z elements the difference of the screening values for relativistic and nonrelativistic form factors (fig. 13) might give an upper limit of about 0.1% for the uncertainty of the total absorption cross section as far as the pair production is concerned. The uncertainty of the Compton cross section should be at most of the same magnitude for energies around 10 MeV (see sec. 2.2) and less for higher energies. The triplet cross section constitutes not more than 20% of the total cross section (for Li at high energies, fig. 2). Assuming an accuracy of the triplet cross section of 1%, this would result in an uncertainty of 0.2% of the total cross section. The foregoing estimates are rather conservative since the fraction of the total absorption cross section which is due to triplet production decreases with increasing atomic number as well as the fraction due to Compton effect. The atomic cross sections for light elements are therefore estimated to be accurate to approximately 0.2% of the total absorption cross section.

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Table I: Calculated atomic cross sections, $\sigma_a(k)$, in the energy range of 10 to 350 MeV for Z = 3, 4, 6, 8, 13, 20, 29, 50, 73, 82. Columns 3-6 give the partial cross sections $\sigma_{ph}(k)$, $\sigma_c(k)$, $\sigma_t(k)$ and $\sigma_p(k)$.

Z= 3.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	1.7621+02	3.9286-05	1.5346+02	3.5116+00	1.9245+01
12.0	1.6048+02	3.2206-05	1.3422+02	4.3744+00	2.1889+01
14.0	1.4896+02	2.7282-05	1.1963+02	5.1506+00	2.4174+01
16.0	1.4019+02	2.3662-05	1.0815+02	5.8532+00	2.6183+01
18.0	1.3332+02	2.0888-05	9.8856+01	6.4937+00	2.7973+01
20.0	1.2783+02	1.8695-05	9.1159+01	7.0806+00	2.9587+01
22.0	1.2335+02	1.6919-05	8.4671+01	7.6210+00	3.1054+01
24.0	1.1964+02	1.5450-05	7.9119+01	8.1212+00	3.2397+01
26.0	1.1653+02	1.4216-05	7.4309+01	8.5865+00	3.3635+01
28.0	1.1390+02	1.3164-05	7.0098+01	9.0212+00	3.4781+01
30.0	1.1165+02	1.2257-05	6.6376+01	9.4288+00	3.5848+01
32.0	1.0972+02	1.1467-05	6.3061+01	9.8123+00	3.6844+01
34.0	1.0804+02	1.0773-05	6.0088+01	1.0174+01	3.7778+01
36.0	1.0658+02	1.0157-05	5.7404+01	1.0517+01	3.8657+01
38.0	1.0530+02	9.6087-06	5.4968+01	1.0843+01	3.9485+01
40.0	1.0417+02	9.1161-06	5.2747+01	1.1152+01	4.0268+01
45.0	1.0188+02	8.0805-06	4.7960+01	1.1864+01	4.2054+01
50.0	1.0016+02	7.2561-06	4.4025+01	1.2503+01	4.3633+01
55.0	9.8850+01	6.5843-06	4.0728+01	1.3080+01	4.5042+01
60.0	9.7838+01	6.0263-06	3.7923+01	1.3606+01	4.6310+01
65.0	9.7053+01	5.5555-06	3.5507+01	1.4088+01	4.7459+01
70.0	9.6442+01	5.1529-06	3.3403+01	1.4532+01	4.8506+01
75.0	9.5964+01	4.8048-06	3.1553+01	1.4944+01	4.9466+01
80.0	9.5590+01	4.5006-06	2.9912+01	1.5328+01	5.0351+01
85.0	9.5299+01	4.2327-06	2.8444+01	1.5686+01	5.1169+01
90.0	9.5073+01	3.9949-06	2.7122+01	1.6022+01	5.1929+01
95.0	9.4901+01	3.7824-06	2.5926+01	1.6338+01	5.2636+01
100.0	9.4773+01	3.5913-06	2.4839+01	1.6636+01	5.3298+01
125.0	9.4569+01	2.8672-06	2.0605+01	1.7908+01	5.6055+01
150.0	9.4751+01	2.3861-06	1.7680+01	1.8913+01	5.8158+01
175.0	9.5086+01	2.0432-06	1.5523+01	1.9735+01	5.9828+01
200.0	9.5480+01	1.7865-06	1.3862+01	2.0425+01	6.1194+01
225.0	9.5895+01	1.5871-06	1.2543+01	2.1015+01	6.2337+01
250.0	9.6308+01	1.4278-06	1.1471+01	2.1527+01	6.3310+01
275.0	9.6710+01	1.2975-06	1.0580+01	2.1979+01	6.4151+01
300.0	9.7094+01	1.1890-06	9.8268+00	2.2381+01	6.4886+01
325.0	9.7458+01	1.0972-06	9.1810+00	2.2742+01	6.5535+01
350.0	9.7802+01	1.0186-06	8.6205+00	2.3068+01	6.6113+01

Table I: Continued

Z= 4.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	2.4350+02	1.6129-04	2.0461+02	4.6822+00	3.4203+01
12.0	2.2369+02	1.3217-04	1.7896+02	5.8326+00	3.8896+01
14.0	2.0933+02	1.1193-04	1.5951+02	6.8673+00	4.2948+01
16.0	1.9851+02	9.7051-05	1.4420+02	7.8041+00	4.6506+01
18.0	1.9014+02	8.5658-05	1.3181+02	8.6579+00	4.9674+01
20.0	1.8351+02	7.6656-05	1.2155+02	9.4402+00	5.2523+01
22.0	1.7816+02	6.9363-05	1.1289+02	1.0160+01	5.5110+01
24.0	1.7379+02	6.3336-05	1.0549+02	1.0827+01	5.7474+01
26.0	1.7017+02	5.8272-05	9.9079+01	1.1446+01	5.9648+01
28.0	1.6715+02	5.3956-05	9.3464+01	1.2025+01	6.1658+01
30.0	1.6459+02	5.0236-05	8.8502+01	1.2567+01	6.3525+01
32.0	1.6243+02	4.6995-05	8.4082+01	1.3077+01	6.5266+01
34.0	1.6057+02	4.4146-05	8.0117+01	1.3559+01	6.6896+01
36.0	1.5898+02	4.1623-05	7.6538+01	1.4014+01	6.8425+01
38.0	1.5760+02	3.9373-05	7.3291+01	1.4446+01	6.9865+01
40.0	1.5641+02	3.7353-05	7.0329+01	1.4857+01	7.1224+01
45.0	1.5406+02	3.3107-05	6.3946+01	1.5801+01	7.4315+01
50.0	1.5238+02	2.9728-05	5.8700+01	1.6646+01	7.7039+01
55.0	1.5118+02	2.6974-05	5.4304+01	1.7408+01	7.9466+01
60.0	1.5031+02	2.4687-05	5.0564+01	1.8102+01	8.1647+01
65.0	1.4970+02	2.2758-05	4.7343+01	1.8736+01	8.3622+01
70.0	1.4928+02	2.1108-05	4.4538+01	1.9321+01	8.5421+01
75.0	1.4900+02	1.9681-05	4.2071+01	1.9863+01	8.7069+01
80.0	1.4884+02	1.8435-05	3.9882+01	2.0367+01	8.8589+01
85.0	1.4876+02	1.7337-05	3.7925+01	2.0837+01	8.9995+01
90.0	1.4874+02	1.6363-05	3.6163+01	2.1278+01	9.1302+01
95.0	1.4878+02	1.5492-05	3.4568+01	2.1693+01	9.2521+01
100.0	1.4886+02	1.4709-05	3.3118+01	2.2084+01	9.3661+01
125.0	1.4966+02	1.1743-05	2.7474+01	2.3752+01	9.8435+01
150.0	1.5075+02	9.7720-06	2.3573+01	2.5071+01	1.0211+02
175.0	1.5189+02	8.3676-06	2.0697+01	2.6152+01	1.0504+02
200.0	1.5301+02	7.3161-06	1.8482+01	2.7061+01	1.0746+02
225.0	1.5406+02	6.4994-06	1.6724+01	2.7841+01	1.0950+02
250.0	1.5505+02	5.8467-06	1.5294+01	2.8519+01	1.1124+02
275.0	1.5598+02	5.3132-06	1.4106+01	2.9116+01	1.1275+02
300.0	1.5683+02	4.8689-06	1.3102+01	2.9648+01	1.1408+02
325.0	1.5762+02	4.4931-06	1.2241+01	3.0125+01	1.1525+02
350.0	1.5835+02	4.1712-06	1.1494+01	3.0556+01	1.1630+02

Table I: Continued

Z= 6.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	3.9082+02	1.1637-03	3.0692+02	7.0232+00	7.6883+01
12.0	3.6458+02	9.5283-04	2.6844+02	8.7486+00	8.7390+01
14.0	3.4601+02	8.0645-04	2.3927+02	1.0300+01	9.6442+01
16.0	3.3238+02	6.9895-04	2.1630+02	1.1705+01	1.0437+02
18.0	3.2211+02	6.1669-04	1.9771+02	1.2984+01	1.1141+02
20.0	3.1421+02	5.5172-04	1.8232+02	1.4156+01	1.1773+02
22.0	3.0803+02	4.9911-04	1.6934+02	1.5234+01	1.2345+02
24.0	3.0314+02	4.5565-04	1.5824+02	1.6231+01	1.2867+02
26.0	2.9923+02	4.1915-04	1.4862+02	1.7158+01	1.3345+02
28.0	2.9609+02	3.8805-04	1.4020+02	1.8022+01	1.3787+02
30.0	2.9356+02	3.6125-04	1.3275+02	1.8832+01	1.4197+02
32.0	2.9150+02	3.3791-04	1.2612+02	1.9592+01	1.4579+02
34.0	2.8984+02	3.1739-04	1.2018+02	2.0309+01	1.4935+02
36.0	2.8849+02	2.9923-04	1.1481+02	2.0988+01	1.5270+02
38.0	2.8741+02	2.8303-04	1.0994+02	2.1630+01	1.5584+02
40.0	2.8654+02	2.6849-04	1.0549+02	2.2241+01	1.5881+02
45.0	2.8511+02	2.3793-04	9.5920+01	2.3643+01	1.6555+02
50.0	2.8443+02	2.1362-04	8.8051+01	2.4896+01	1.7149+02
55.0	2.8427+02	1.9381-04	8.1456+01	2.6026+01	1.7679+02
60.0	2.8446+02	1.7737-04	7.5846+01	2.7052+01	1.8156+02
65.0	2.8489+02	1.6349-04	7.1014+01	2.7991+01	1.8589+02
70.0	2.8550+02	1.5163-04	6.6807+01	2.8855+01	1.8984+02
75.0	2.8624+02	1.4137-04	6.3107+01	2.9656+01	1.9347+02
80.0	2.8705+02	1.3242-04	5.9823+01	3.0400+01	1.9683+02
85.0	2.8792+02	1.2453-04	5.6887+01	3.1095+01	1.9993+02
90.0	2.8882+02	1.1752-04	5.4244+01	3.1746+01	2.0283+02
95.0	2.8974+02	1.1127-04	5.1853+01	3.2358+01	2.0553+02
100.0	2.9067+02	1.0564-04	4.9678+01	3.2935+01	2.0806+02
125.0	2.9529+02	8.4327-05	4.1211+01	3.5395+01	2.1868+02
150.0	2.9956+02	7.0169-05	3.5359+01	3.7335+01	2.2687+02
175.0	3.0338+02	6.0081-05	3.1045+01	3.8919+01	2.3341+02
200.0	3.0676+02	5.2530-05	2.7723+01	4.0244+01	2.3879+02
225.0	3.0976+02	4.6664-05	2.5087+01	4.1374+01	2.4330+02
250.0	3.1243+02	4.1977-05	2.2941+01	4.2351+01	2.4714+02
275.0	3.1483+02	3.8146-05	2.1159+01	4.3208+01	2.5046+02
300.0	3.1698+02	3.4955-05	1.9654+01	4.3966+01	2.5337+02
325.0	3.1893+02	3.2257-05	1.8362+01	4.4642+01	2.5592+02
350.0	3.2070+02	2.9946-05	1.7241+01	4.5250+01	2.5820+02

Table I: Continued

Z= 8.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	5.5508+02	4.6661-03	4.0922+02	9.3638+00	1.3649+02
12.0	5.2465+02	3.8176-03	3.5792+02	1.1664+01	1.5505+02
14.0	5.0378+02	3.2293-03	3.1902+02	1.3731+01	1.7102+02
16.0	4.8899+02	2.7977-03	2.8841+02	1.5602+01	1.8498+02
18.0	4.7828+02	2.4676-03	2.6362+02	1.7305+01	1.9736+02
20.0	4.7041+02	2.2070-03	2.4309+02	1.8863+01	2.0845+02
22.0	4.6457+02	1.9961-03	2.2579+02	2.0296+01	2.1848+02
24.0	4.6023+02	1.8220-03	2.1098+02	2.1620+01	2.2762+02
26.0	4.5702+02	1.6757-03	1.9816+02	2.2850+01	2.3601+02
28.0	4.5468+02	1.5512-03	1.8693+02	2.3997+01	2.4375+02
30.0	4.5301+02	1.4439-03	1.7700+02	2.5071+01	2.5093+02
32.0	4.5187+02	1.3504-03	1.6816+02	2.6079+01	2.5762+02
34.0	4.5114+02	1.2683-03	1.6023+02	2.7029+01	2.6387+02
36.0	4.5074+02	1.1956-03	1.5308+02	2.7926+01	2.6974+02
38.0	4.5061+02	1.1308-03	1.4658+02	2.8777+01	2.7525+02
40.0	4.5070+02	1.0726-03	1.4066+02	2.9584+01	2.8046+02
45.0	4.5162+02	9.5044-04	1.2789+02	3.1437+01	2.9229+02
50.0	4.5322+02	8.5322-04	1.1740+02	3.3091+01	3.0273+02
55.0	4.5524+02	7.7403-04	1.0861+02	3.4582+01	3.1205+02
60.0	4.5752+02	7.0829-04	1.0113+02	3.5936+01	3.2045+02
65.0	4.5994+02	6.5284-04	9.4685+01	3.7174+01	3.2808+02
70.0	4.6243+02	6.0545-04	8.9076+01	3.8313+01	3.3504+02
75.0	4.6494+02	5.6446-04	8.4142+01	3.9367+01	3.4143+02
80.0	4.6743+02	5.2867-04	7.9765+01	4.0347+01	3.4732+02
85.0	4.6989+02	4.9715-04	7.5850+01	4.1260+01	3.5278+02
90.0	4.7229+02	4.6918-04	7.2326+01	4.2115+01	3.5785+02
95.0	4.7463+02	4.4418-04	6.9137+01	4.2918+01	3.6258+02
100.0	4.7691+02	4.2172-04	6.6237+01	4.3675+01	3.6700+02
125.0	4.8732+02	3.3659-04	5.4947+01	4.6890+01	3.8548+02
150.0	4.9614+02	2.8006-04	4.7145+01	4.9412+01	3.9959+02
175.0	5.0362+02	2.3979-04	4.1394+01	5.1461+01	4.1076+02
200.0	5.1000+02	2.0964-04	3.6965+01	5.3167+01	4.1986+02
225.0	5.1551+02	1.8622-04	3.3449+01	5.4614+01	4.2745+02
250.0	5.2031+02	1.6752-04	3.0588+01	5.5861+01	4.3386+02
275.0	5.2455+02	1.5222-04	2.8213+01	5.6950+01	4.3938+02
300.0	5.2830+02	1.3949-04	2.6205+01	5.7910+01	4.4418+02
325.0	5.3164+02	1.2872-04	2.4483+01	5.8763+01	4.4839+02
350.0	5.3465+02	1.1949-04	2.2988+01	5.9528+01	4.5213+02

Table I: Continued

Z=13.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	1.0389+03	4.7052-02	6.6498+02	1.5210+01	3.5870+02
12.0	1.0076+03	3.8427-02	5.8163+02	1.8940+01	4.0699+02
14.0	9.8916+02	3.2462-02	5.1842+02	2.2289+01	4.4842+02
16.0	9.7862+02	2.8095-02	4.6866+02	2.5316+01	4.8462+02
18.0	9.7316+02	2.4760-02	4.2838+02	2.8068+01	5.1669+02
20.0	9.7106+02	2.2131-02	3.9502+02	3.0583+01	5.4543+02
22.0	9.7125+02	2.0006-02	3.6691+02	3.2893+01	5.7143+02
24.0	9.7302+02	1.8252-02	3.4285+02	3.5025+01	5.9513+02
26.0	9.7590+02	1.6781-02	3.2201+02	3.7003+01	6.1688+02
28.0	9.7957+02	1.5529-02	3.0376+02	3.8846+01	6.3695+02
30.0	9.8378+02	1.4450-02	2.8763+02	4.0569+01	6.5556+02
32.0	9.8836+02	1.3512-02	2.7327+02	4.2186+01	6.7289+02
34.0	9.9319+02	1.2687-02	2.6038+02	4.3708+01	6.8909+02
36.0	9.9817+02	1.1958-02	2.4875+02	4.5144+01	7.0427+02
38.0	1.0033+03	1.1307-02	2.3819+02	4.6504+01	7.1854+02
40.0	1.0084+03	1.0724-02	2.2857+02	4.7793+01	7.3200+02
45.0	1.0211+03	9.4991-03	2.0783+02	5.0746+01	7.6255+02
50.0	1.0336+03	8.5251-03	1.9078+02	5.3374+01	7.8940+02
55.0	1.0455+03	7.7321-03	1.7649+02	5.5734+01	8.1324+02
60.0	1.0568+03	7.0741-03	1.6433+02	5.7870+01	8.3460+02
65.0	1.0676+03	6.5192-03	1.5386+02	5.9816+01	8.5388+02
70.0	1.0777+03	6.0451-03	1.4475+02	6.1602+01	8.7138+02
75.0	1.0873+03	5.6352-03	1.3673+02	6.3248+01	8.8736+02
80.0	1.0964+03	5.2774-03	1.2962+02	6.4772+01	9.0202+02
85.0	1.1050+03	4.9622-03	1.2326+02	6.6189+01	9.1553+02
90.0	1.1131+03	4.6826-03	1.1753+02	6.7512+01	9.2804+02
95.0	1.1207+03	4.4329-03	1.1235+02	6.8750+01	9.3964+02
100.0	1.1280+03	4.2084-03	1.0763+02	6.9912+01	9.5046+02
125.0	1.1593+03	3.3580-03	8.9290+01	7.4820+01	9.9518+02
150.0	1.1841+03	2.7936-03	7.6611+01	7.8634+01	1.0288+03
175.0	1.2042+03	2.3915-03	6.7265+01	8.1711+01	1.0553+03
200.0	1.2210+03	2.0907-03	6.0067+01	8.4263+01	1.0766+03
225.0	1.2351+03	1.8570-03	5.4354+01	8.6424+01	1.0944+03
250.0	1.2473+03	1.6704-03	4.9706+01	8.8283+01	1.1093+03
275.0	1.2579+03	1.5178-03	4.5845+01	8.9907+01	1.1221+03
300.0	1.2672+03	1.3908-03	4.2583+01	9.1339+01	1.1333+03
325.0	1.2754+03	1.2834-03	3.9784+01	9.2614+01	1.1430+03
350.0	1.2828+03	1.1914-03	3.7356+01	9.3759+01	1.1516+03

Z=20.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	1.8894+03	3.5067-01	1.0231+03	2.3372+01	8.4264+02
12.0	1.8792+03	2.8575-01	8.9481+02	2.9089+01	9.5498+02
14.0	1.8834+03	2.4100-01	7.9756+02	3.4215+01	1.0514+03
16.0	1.8957+03	2.0831-01	7.2102+02	3.8840+01	1.1356+03
18.0	1.9124+03	1.8340-01	6.5904+02	4.3041+01	1.2102+03
20.0	1.9317+03	1.6380-01	6.0773+02	4.6876+01	1.2769+03
22.0	1.9523+03	1.4797-01	5.6447+02	5.0393+01	1.3372+03
24.0	1.9733+03	1.3492-01	5.2746+02	5.3635+01	1.3921+03
26.0	1.9945+03	1.2398-01	4.9539+02	5.6639+01	1.4424+03
28.0	2.0155+03	1.1468-01	4.6732+02	5.9434+01	1.4886+03
30.0	2.0361+03	1.0668-01	4.4251+02	6.2044+01	1.5315+03
32.0	2.0562+03	9.9716-02	4.2041+02	6.4489+01	1.5712+03
34.0	2.0758+03	9.3606-02	4.0058+02	6.6788+01	1.6083+03
36.0	2.0947+03	8.8201-02	3.8269+02	6.8955+01	1.6430+03
38.0	2.1131+03	8.3386-02	3.6645+02	7.1003+01	1.6756+03
40.0	2.1309+03	7.9068-02	3.5164+02	7.2943+01	1.7062+03
45.0	2.1727+03	7.0005-02	3.1973+02	7.7378+01	1.7755+03
50.0	2.2111+03	6.2805-02	2.9350+02	8.1316+01	1.8362+03
55.0	2.2465+03	5.6946-02	2.7152+02	8.4847+01	1.8900+03
60.0	2.2791+03	5.2087-02	2.5282+02	8.8038+01	1.9382+03
65.0	2.3094+03	4.7992-02	2.3671+02	9.0942+01	1.9817+03
70.0	2.3374+03	4.4494-02	2.2269+02	9.3603+01	2.0211+03
75.0	2.3635+03	4.1470-02	2.1036+02	9.6055+01	2.0571+03
80.0	2.3879+03	3.8832-02	1.9941+02	9.8324+01	2.0901+03
85.0	2.4107+03	3.6509-02	1.8962+02	1.0043+02	2.1206+03
90.0	2.4320+03	3.4448-02	1.8081+02	1.0240+02	2.1488+03
95.0	2.4521+03	3.2607-02	1.7284+02	1.0424+02	2.1750+03
100.0	2.4709+03	3.0953-02	1.6559+02	1.0597+02	2.1994+03
125.0	2.5510+03	2.4691-02	1.3737+02	1.1325+02	2.3004+03
150.0	2.6134+03	2.0536-02	1.1786+02	1.1891+02	2.3766+03
175.0	2.6634+03	1.7578-02	1.0348+02	1.2347+02	2.4364+03
200.0	2.7046+03	1.5365-02	9.2411+01	1.2725+02	2.4849+03
225.0	2.7392+03	1.3646-02	8.3622+01	1.3044+02	2.5251+03
250.0	2.7687+03	1.2274-02	7.6471+01	1.3318+02	2.5591+03
275.0	2.7943+03	1.1152-02	7.0531+01	1.3558+02	2.5882+03
300.0	2.8166+03	1.0218-02	6.5512+01	1.3768+02	2.6134+03
325.0	2.8363+03	9.4286-03	6.1207+01	1.3956+02	2.6356+03
350.0	2.8539+03	8.7523-03	5.7470+01	1.4124+02	2.6552+03

Table I: Continued

Z=29.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	3.2734+03	1.9124+00	1.4834+03	3.3824+01	1.7542+03
12.0	3.3263+03	1.5545+00	1.2975+03	4.2074+01	1.9852+03
14.0	3.3904+03	1.3086+00	1.1565+03	4.9462+01	2.1832+03
16.0	3.4587+03	1.1295+00	1.0455+03	5.6120+01	2.3559+03
18.0	3.5275+03	9.9327-01	9.5561+02	6.2159+01	2.5087+03
20.0	3.5950+03	8.8626-01	8.8121+02	6.7665+01	2.6453+03
22.0	3.6605+03	7.9999-01	8.1848+02	7.2708+01	2.7685+03
24.0	3.7234+03	7.2898-01	7.6482+02	7.7351+01	2.8805+03
26.0	3.7838+03	6.6951-01	7.1832+02	8.1647+01	2.9831+03
28.0	3.8414+03	6.1899-01	6.7761+02	8.5640+01	3.0776+03
30.0	3.8965+03	5.7555-01	6.4164+02	8.9365+01	3.1650+03
32.0	3.9491+03	5.3779-01	6.0959+02	9.2850+01	3.2461+03
34.0	3.9993+03	5.0468-01	5.8085+02	9.6123+01	3.3219+03
36.0	4.0473+03	4.7539-01	5.5490+02	9.9205+01	3.3927+03
38.0	4.0931+03	4.4932-01	5.3136+02	1.0211+02	3.4591+03
40.0	4.1368+03	4.2595-01	5.0988+02	1.0487+02	3.5217+03
45.0	4.2383+03	3.7694-01	4.6361+02	1.1115+02	3.6632+03
50.0	4.3297+03	3.3803-01	4.2558+02	1.1671+02	3.7871+03
55.0	4.4126+03	3.0640-01	3.9370+02	1.2168+02	3.8969+03
60.0	4.4881+03	2.8018-01	3.6659+02	1.2615+02	3.9951+03
65.0	4.5573+03	2.5809-01	3.4323+02	1.3022+02	4.0836+03
70.0	4.6208+03	2.3922-01	3.2290+02	1.3393+02	4.1637+03
75.0	4.6794+03	2.2293-01	3.0501+02	1.3734+02	4.2368+03
80.0	4.7336+03	2.0871-01	2.8915+02	1.4048+02	4.3038+03
85.0	4.7839+03	1.9620-01	2.7496+02	1.4340+02	4.3653+03
90.0	4.8307+03	1.8510-01	2.6218+02	1.4611+02	4.4222+03
95.0	4.8743+03	1.7519-01	2.5062+02	1.4864+02	4.4749+03
100.0	4.9152+03	1.6629-01	2.4011+02	1.5101+02	4.5239+03
125.0	5.0860+03	1.3259-01	1.9918+02	1.6094+02	4.7258+03
150.0	5.2161+03	1.1025-01	1.7090+02	1.6855+02	4.8766+03
175.0	5.3189+03	9.4355-02	1.5005+02	1.7463+02	4.9941+03
200.0	5.4023+03	8.2463-02	1.3400+02	1.7962+02	5.0886+03
225.0	5.4716+03	7.3234-02	1.2125+02	1.8381+02	5.1665+03
250.0	5.5301+03	6.5862-02	1.1088+02	1.8738+02	5.2318+03
275.0	5.5804+03	5.9838-02	1.0227+02	1.9047+02	5.2876+03
300.0	5.6241+03	5.4824-02	9.4993+01	1.9318+02	5.3359+03
325.0	5.6623+03	5.0586-02	8.8750+01	1.9557+02	5.3779+03
350.0	5.6962+03	4.6955-02	8.3332+01	1.9771+02	5.4151+03

Z=50.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	7.7054+03	2.1539+01	2.5576+03	5.8026+01	5.0682+03
12.0	8.0353+03	1.7424+01	2.2370+03	7.2092+01	5.7088+03
14.0	8.3515+03	1.4616+01	1.9939+03	8.4649+01	6.2583+03
16.0	8.6491+03	1.2580+01	1.8025+03	9.5932+01	6.7381+03
18.0	8.9275+03	1.1039+01	1.6476+03	1.0614+02	7.1627+03
20.0	9.1871+03	9.8319+00	1.5193+03	1.1541+02	7.5425+03
22.0	9.4290+03	8.8616+00	1.4112+03	1.2389+02	7.8851+03
24.0	9.6548+03	8.0648+00	1.3186+03	1.3167+02	8.1964+03
26.0	9.8659+03	7.3989+00	1.2385+03	1.3885+02	8.4812+03
28.0	1.0064+04	6.8342+00	1.1683+03	1.4551+02	8.7431+03
30.0	1.0249+04	6.3493+00	1.1063+03	1.5171+02	8.9852+03
32.0	1.0424+04	5.9285+00	1.0510+03	1.5750+02	9.2097+03
34.0	1.0589+04	5.5598+00	1.0015+03	1.6293+02	9.4188+03
36.0	1.0744+04	5.2343+00	9.5673+02	1.6802+02	9.6141+03
38.0	1.0891+04	4.9446+00	9.1613+02	1.7283+02	9.7971+03
40.0	1.1030+04	4.6853+00	8.7911+02	1.7736+02	9.9689+03
45.0	1.1348+04	4.1420+00	7.9933+02	1.8768+02	1.0357+04
50.0	1.1630+04	3.7115+00	7.3376+02	1.9678+02	1.0695+04
55.0	1.1882+04	3.3620+00	6.7880+02	2.0489+02	1.0995+04
60.0	1.2109+04	3.0725+00	6.3205+02	2.1217+02	1.1261+04
65.0	1.2315+04	2.8290+00	5.9178+02	2.1876+02	1.1501+04
70.0	1.2502+04	2.6211+00	5.5672+02	2.2477+02	1.1718+04
75.0	1.2674+04	2.4417+00	5.2589+02	2.3027+02	1.1915+04
80.0	1.2832+04	2.2853+00	4.9853+02	2.3534+02	1.2096+04
85.0	1.2978+04	2.1477+00	4.7406+02	2.4003+02	1.2262+04
90.0	1.3113+04	2.0257+00	4.5204+02	2.4439+02	1.2414+04
95.0	1.3238+04	1.9169+00	4.3210+02	2.4844+02	1.2556+04
100.0	1.3356+04	1.8191+00	4.1398+02	2.5224+02	1.2688+04
125.0	1.3841+04	1.4494+00	3.4342+02	2.6808+02	1.3228+04
150.0	1.4207+04	1.2046+00	2.9466+02	2.8018+02	1.3631+04
175.0	1.4494+04	1.0305+00	2.5871+02	2.8981+02	1.3944+04
200.0	1.4726+04	9.0040-01	2.3103+02	2.9770+02	1.4196+04
225.0	1.4918+04	7.9945-01	2.0905+02	3.0431+02	1.4404+04
250.0	1.5080+04	7.1885-01	1.9118+02	3.0995+02	1.4578+04
275.0	1.5218+04	6.5302-01	1.7633+02	3.1483+02	1.4726+04
300.0	1.5338+04	5.9823-01	1.6378+02	3.1910+02	1.4855+04
325.0	1.5443+04	5.5193-01	1.5302+02	3.2287+02	1.4967+04
350.0	1.5536+04	5.1227-01	1.4368+02	3.2623+02	1.5066+04

Z=73.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	1.4258+04	1.1040+02	3.7341+03	8.4249+01	1.0329+04
12.0	1.5029+04	8.8941+01	3.2661+03	1.0455+02	1.1569+04
14.0	1.5744+04	7.4376+01	2.9111+03	1.2264+02	1.2636+04
16.0	1.6405+04	6.3865+01	2.6317+03	1.3885+02	1.3570+04
18.0	1.7013+04	5.5931+01	2.4055+03	1.5348+02	1.4398+04
20.0	1.7575+04	4.9737+01	2.2182+03	1.6675+02	1.5141+04
22.0	1.8095+04	4.4769+01	2.0603+03	1.7885+02	1.5811+04
24.0	1.8578+04	4.0697+01	1.9252+03	1.8993+02	1.6422+04
26.0	1.9027+04	3.7301+01	1.8082+03	2.0014+02	1.6981+04
28.0	1.9446+04	3.4426+01	1.7057+03	2.0959+02	1.7496+04
30.0	1.9838+04	3.1960+01	1.6152+03	2.1837+02	1.7972+04
32.0	2.0206+04	2.9822+01	1.5345+03	2.2655+02	1.8415+04
34.0	2.0551+04	2.7952+01	1.4621+03	2.3420+02	1.8827+04
36.0	2.0877+04	2.6301+01	1.3968+03	2.4138+02	1.9212+04
38.0	2.1184+04	2.4834+01	1.3376+03	2.4813+02	1.9574+04
40.0	2.1474+04	2.3522+01	1.2835+03	2.5449+02	1.9913+04
45.0	2.2136+04	2.0776+01	1.1670+03	2.6892+02	2.0679+04
50.0	2.2720+04	1.8603+01	1.0713+03	2.8160+02	2.1348+04
55.0	2.3239+04	1.6841+01	9.9105+02	2.9287+02	2.1939+04
60.0	2.3706+04	1.5384+01	9.2279+02	3.0295+02	2.2465+04
65.0	2.4127+04	1.4158+01	8.6400+02	3.1206+02	2.2937+04
70.0	2.4509+04	1.3113+01	8.1281+02	3.2034+02	2.3363+04
75.0	2.4858+04	1.2212+01	7.6780+02	3.2791+02	2.3751+04
80.0	2.5179+04	1.1426+01	7.2785+02	3.3487+02	2.4104+04
85.0	2.5473+04	1.0736+01	6.9213+02	3.4129+02	2.4429+04
90.0	2.5745+04	1.0124+01	6.5997+02	3.4724+02	2.4728+04
95.0	2.5998+04	9.5776+00	6.3087+02	3.5278+02	2.5005+04
100.0	2.6233+04	9.0875+00	6.0441+02	3.5795+02	2.5262+04
125.0	2.7201+04	7.2357+00	5.0140+02	3.7944+02	2.6313+04
150.0	2.7925+04	6.0108+00	4.3020+02	3.9576+02	2.7093+04
175.0	2.8490+04	5.1405+00	3.7772+02	4.0868+02	2.7698+04
200.0	2.8944+04	4.4903+00	3.3730+02	4.1922+02	2.8183+04
225.0	2.9318+04	3.9861+00	3.0522+02	4.2802+02	2.8581+04
250.0	2.9633+04	3.5837+00	2.7912+02	4.3550+02	2.8914+04
275.0	2.9901+04	3.2551+00	2.5744+02	4.4196+02	2.9198+04
300.0	3.0133+04	2.9816+00	2.3912+02	4.4760+02	2.9444+04
325.0	3.0335+04	2.7506+00	2.2341+02	4.5257+02	2.9656+04
350.0	3.0514+04	2.5528+00	2.0977+02	4.5700+02	2.9845+04

Z=82.

E (MEV)	TOTAL (MB)	PHOTO (MB)	COMPTON (MB)	TRIPLET (MB)	PAIR (MB)
10.0	1.7201+04	1.8087+02	4.1945+03	9.4423+01	1.2731+04
12.0	1.8163+04	1.4552+02	3.6687+03	1.1713+02	1.4232+04
14.0	1.9055+04	1.2156+02	3.2700+03	1.3733+02	1.5526+04
16.0	1.9878+04	1.0429+02	2.9562+03	1.5543+02	1.6662+04
18.0	2.0637+04	9.1275+01	2.7021+03	1.7174+02	1.7672+04
20.0	2.1337+04	8.1121+01	2.4917+03	1.8653+02	1.8577+04
22.0	2.1984+04	7.2985+01	2.3143+03	1.9999+02	1.9397+04
24.0	2.2584+04	6.6321+01	2.1626+03	2.1232+02	2.0143+04
26.0	2.3142+04	6.0766+01	2.0311+03	2.2367+02	2.0827+04
28.0	2.3663+04	5.6065+01	1.9160+03	2.3417+02	2.1457+04
30.0	2.4149+04	5.2036+01	1.8143+03	2.4392+02	2.2039+04
32.0	2.4606+04	4.8545+01	1.7237+03	2.5300+02	2.2580+04
34.0	2.5034+04	4.5491+01	1.6424+03	2.6148+02	2.3085+04
36.0	2.5437+04	4.2797+01	1.5690+03	2.6944+02	2.3556+04
38.0	2.5817+04	4.0404+01	1.5025+03	2.7693+02	2.3997+04
40.0	2.6176+04	3.8263+01	1.4417+03	2.8398+02	2.4412+04
45.0	2.6994+04	3.3786+01	1.3109+03	2.9996+02	2.5349+04
50.0	2.7714+04	3.0244+01	1.2034+03	3.1400+02	2.6166+04
55.0	2.8354+04	2.7374+01	1.1132+03	3.2645+02	2.6887+04
60.0	2.8928+04	2.5000+01	1.0366+03	3.3760+02	2.7529+04
65.0	2.9446+04	2.3005+01	9.7053+02	3.4767+02	2.8105+04
70.0	2.9917+04	2.1305+01	9.1302+02	3.5681+02	2.8625+04
75.0	3.0346+04	1.9838+01	8.6246+02	3.6516+02	2.9098+04
80.0	3.0739+04	1.8560+01	8.1759+02	3.7284+02	2.9530+04
85.0	3.1100+04	1.7437+01	7.7746+02	3.7992+02	2.9926+04
90.0	3.1435+04	1.6441+01	7.4134+02	3.8647+02	3.0290+04
95.0	3.1744+04	1.5554+01	7.0865+02	3.9257+02	3.0628+04
100.0	3.2033+04	1.4757+01	6.7893+02	3.9826+02	3.0941+04
125.0	3.3219+04	1.1747+01	5.6321+02	4.2189+02	3.2223+04
150.0	3.4106+04	9.7567+00	4.8324+02	4.3981+02	3.3174+04
175.0	3.4797+04	8.3430+00	4.2428+02	4.5398+02	3.3911+04
200.0	3.5353+04	7.2871+00	3.7889+02	4.6552+02	3.4502+04
225.0	3.5811+04	6.4684+00	3.4285+02	4.7515+02	3.4987+04
250.0	3.6195+04	5.8151+00	3.1353+02	4.8333+02	3.5393+04
275.0	3.6524+04	5.2816+00	2.8918+02	4.9038+02	3.5739+04
300.0	3.6808+04	4.8378+00	2.6860+02	4.9654+02	3.6038+04
325.0	3.7055+04	4.4628+00	2.5095+02	5.0196+02	3.6298+04
350.0	3.7274+04	4.1417+00	2.3563+02	5.0679+02	3.6527+04

Table II: Screening cross sections ΔS for pair production in the nuclear Coulomb field. Column 2-4 give the screening values obtained with the different sets of form factors as described in section 3.3: THF: Thomas-Fermi form factors, NONREL.: nonrelativistic form factors, REL.: relativistic form factors.

SCREENING CORRECTIONS FOR Z= 3

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	5.3671-02	1.8306-03	1.8566-03
10.0	6.6796-02	2.7822-03	2.7998-03
15.0	1.4868-01	1.3005-02	1.2824-02
20.0	2.5218-01	3.5964-02	3.5200-02
25.0	3.7130-01	7.5146-02	7.3246-02
50.0	1.0877+00	5.2386-01	5.0736-01
75.0	1.8810+00	1.2617+00	1.2226+00
100.0	2.6880+00	2.1197+00	2.0575+00
125.0	3.4850+00	3.0089+00	2.9258+00
150.0	4.2614+00	3.8892+00	3.7875+00
175.0	5.0126+00	4.7434+00	4.6254+00
200.0	5.7368+00	5.5650+00	5.4326+00
225.0	6.4336+00	6.3519+00	6.2066+00
250.0	7.1042+00	7.1052+00	6.9484+00
275.0	7.7491+00	7.8258+00	7.6586+00
300.0	8.3702+00	8.5161+00	8.3395+00
325.0	8.9691+00	9.1786+00	8.9934+00
350.0	9.5461+00	9.8141+00	9.6211+00

SCREENING CORRECTIONS FOR Z= 4

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	1.1450-01	7.8031-03	7.9905-03
10.0	1.4226-01	1.1719-02	1.1898-02
15.0	3.1388-01	5.1265-02	5.0895-02
20.0	5.2795-01	1.3230-01	1.3049-01
25.0	7.7165-01	2.6070-01	2.5502-01
50.0	2.2086+00	1.4611+00	1.4166+00
75.0	3.7736+00	3.1084+00	3.0238+00
100.0	5.3488+00	4.8421+00	4.7253+00
125.0	6.8916+00	6.5391+00	6.3956+00
150.0	8.3840+00	8.1637+00	7.9953+00
175.0	9.8193+00	9.7091+00	9.5160+00
200.0	1.1196+01	1.1178+01	1.0960+01
225.0	1.2515+01	1.2575+01	1.2332+01
250.0	1.3780+01	1.3907+01	1.3638+01
275.0	1.4992+01	1.5178+01	1.4883+01
300.0	1.6156+01	1.6394+01	1.6075+01
325.0	1.7276+01	1.7560+01	1.7217+01
350.0	1.8352+01	1.8678+01	1.8312+01

SCREENING CORRECTIONS FOR Z= 6

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	3.3221-01	5.5661-02	5.6170-02
10.0	4.1160-01	8.0945-02	8.1354-02
15.0	8.9556-01	3.0522-01	3.0376-01
20.0	1.4876+00	6.9596-01	6.9016-01
25.0	2.1513+00	1.2299+00	1.2178+00
50.0	5.9627+00	5.0030+00	4.9529+00
75.0	1.0020+01	9.2193+00	9.1395+00
100.0	1.4042+01	1.3317+01	1.3210+01
125.0	1.7933+01	1.7219+01	1.7080+01
150.0	2.1660+01	2.0929+01	2.0750+01
175.0	2.5215+01	2.4459+01	2.4235+01
200.0	2.8601+01	2.7822+01	2.7550+01
225.0	3.1826+01	3.1029+01	3.0708+01
250.0	3.4902+01	3.4093+01	3.3724+01
275.0	3.7838+01	3.7022+01	3.6606+01
300.0	4.0646+01	3.9829+01	3.9367+01
325.0	4.3339+01	4.2525+01	4.2018+01
350.0	4.5918+01	4.5110+01	4.4561+01

SCREENING CORRECTIONS FOR Z= 8

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	7.0572-01	2.1647-01	2.0447-01
10.0	8.7241-01	3.0570-01	2.8811-01
15.0	1.8776+00	1.0020+00	9.5091-01
20.0	3.0898+00	2.0453+00	1.9604+00
25.0	4.4347+00	3.3242+00	3.2088+00
50.0	1.2021+01	1.0969+01	1.0755+01
75.0	1.9967+01	1.8832+01	1.8569+01
100.0	2.7758+01	2.6459+01	2.6148+01
125.0	3.5231+01	3.3801+01	3.3430+01
150.0	4.2336+01	4.0834+01	4.0396+01
175.0	4.9074+01	4.7554+01	4.7044+01
200.0	5.5461+01	5.3966+01	5.3384+01
225.0	6.1519+01	6.0080+01	5.9427+01
250.0	6.7278+01	6.5915+01	6.5195+01
275.0	7.2758+01	7.1484+01	7.0700+01
300.0	7.7986+01	7.6811+01	7.5967+01
325.0	8.2987+01	8.1915+01	8.1016+01
350.0	8.7768+01	8.6801+01	8.5849+01

SCREENING CORRECTIONS FOR Z=13

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	2.5042+00	1.5212+00	1.4842+00
10.0	3.0824+00	2.0213+00	1.9722+00
15.0	6.5027+00	5.2543+00	5.1449+00
20.0	1.0528+01	9.2075+00	9.0499+00
25.0	1.4918+01	1.3499+01	1.3307+01
50.0	3.8991+01	3.6947+01	3.6691+01
75.0	6.3533+01	6.1667+01	6.1370+01
100.0	8.7137+01	8.6028+01	8.5689+01
125.0	1.0944+02	1.0929+02	1.0891+02
150.0	1.3039+02	1.3124+02	1.3082+02
175.0	1.5007+02	1.5186+02	1.5141+02
200.0	1.6858+02	1.7126+02	1.7077+02
225.0	1.8602+02	1.8951+02	1.8900+02
250.0	2.0251+02	2.0675+02	2.0620+02
275.0	2.1812+02	2.2304+02	2.2246+02
300.0	2.3295+02	2.3850+02	2.3789+02
325.0	2.4709+02	2.5321+02	2.5257+02
350.0	2.6056+02	2.6721+02	2.6655+02

SCREENING CORRECTIONS FOR Z=20

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	7.6575+00	6.6170+00	6.7534+00
10.0	9.3846+00	8.3523+00	8.4949+00
15.0	1.9423+01	1.8279+01	1.8449+01
20.0	3.0990+01	2.9542+01	2.9758+01
25.0	4.3426+01	4.1783+01	4.2056+01
50.0	1.1003+02	1.0994+02	1.1047+02
75.0	1.7627+02	1.7831+02	1.7902+02
100.0	2.3888+02	2.4237+02	2.4322+02
125.0	2.9724+02	3.0177+02	3.0272+02
150.0	3.5152+02	3.5684+02	3.5788+02
175.0	4.0207+02	4.0804+02	4.0915+02
200.0	4.4931+02	4.5581+02	4.5698+02
225.0	4.9358+02	5.0054+02	5.0177+02
250.0	5.3524+02	5.4261+02	5.4387+02
275.0	5.7453+02	5.8225+02	5.8355+02
300.0	6.1173+02	6.1977+02	6.2109+02
325.0	6.4707+02	6.5540+02	6.5675+02
350.0	6.8067+02	6.8925+02	6.9062+02

SCREENING CORRECTIONS FOR Z=29

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	1.9977+01	1.9171+01	2.0911+01
10.0	2.4383+01	2.3587+01	2.5446+01
15.0	4.9603+01	4.8683+01	5.0957+01
20.0	7.8159+01	7.7417+01	7.9999+01
25.0	1.0851+02	1.0824+02	1.1109+02
50.0	2.6786+02	2.6881+02	2.7293+02
75.0	4.2297+02	4.2363+02	4.2879+02
100.0	5.6729+02	5.6835+02	5.7421+02
125.0	7.0031+02	7.0258+02	7.0888+02
150.0	8.2297+02	8.2695+02	8.3353+02
175.0	9.3645+02	9.4240+02	9.4914+02
200.0	1.0419+03	1.0499+03	1.0567+03
225.0	1.1403+03	1.1504+03	1.1572+03
250.0	1.2326+03	1.2446+03	1.2515+03
275.0	1.3193+03	1.3332+03	1.3401+03
300.0	1.4011+03	1.4169+03	1.4237+03
325.0	1.4787+03	1.4962+03	1.5030+03
350.0	1.5523+03	1.5714+03	1.5782+03

SCREENING CORRECTIONS FOR Z=50

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	8.0708+01	7.5823+01	9.7034+01
10.0	9.7881+01	9.2686+01	1.1587+02
15.0	1.9405+02	1.8704+02	2.1828+02
20.0	3.0035+02	2.9176+02	3.2920+02
25.0	4.1158+02	4.0264+02	4.4513+02
50.0	9.7904+02	9.7778+02	1.0366+03
75.0	1.5134+03	1.5196+03	1.5878+03
100.0	1.9995+03	2.0114+03	2.0860+03
125.0	2.4404+03	2.4573+03	2.5363+03
150.0	2.8421+03	2.8634+03	2.9458+03
175.0	3.2103+03	3.2356+03	3.3207+03
200.0	3.5499+03	3.5788+03	3.6661+03
225.0	3.8649+03	3.8971+03	3.9862+03
250.0	4.1586+03	4.1937+03	4.2844+03
275.0	4.4335+03	4.4714+03	4.5633+03
300.0	4.6920+03	4.7324+03	4.8255+03
325.0	4.9363+03	4.9790+03	5.0730+03
350.0	5.1672+03	5.2120+03	5.3069+03

Table II: Continued

SCREENING CORRECTIONS FOR Z=73

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	2.1139+02	2.0725+02	2.8027+02
10.0	2.5519+02	2.5078+02	3.3072+02
15.0	4.9697+02	4.9285+02	6.0145+02
20.0	7.6009+02	7.5819+02	8.8912+02
25.0	1.0326+03	1.0328+03	1.1822+03
50.0	2.3950+03	2.3999+03	2.6093+03
75.0	3.6481+03	3.6604+03	3.9027+03
100.0	4.7705+03	4.7939+03	5.0573+03
125.0	5.7776+03	5.8135+03	6.0917+03
150.0	6.6880+03	6.7364+03	7.0256+03
175.0	7.5174+03	7.5778+03	7.8755+03
200.0	8.2788+03	8.3581+03	8.6547+03
225.0	8.9821+03	9.0634+03	9.3736+03
250.0	9.6358+03	9.7262+03	1.0041+04
275.0	1.0246+04	1.0345+04	1.0664+04
300.0	1.0818+04	1.0925+04	1.1247+04
325.0	1.1358+04	1.1471+04	1.1797+04
350.0	1.1867+04	1.1986+04	1.2315+04

SCREENING CORRECTIONS FOR Z=82

E (MEV)	THF (MB)	NONREL. (MB)	REL. (MB)
9.0	2.8381+02	2.9239+02	3.9166+02
10.0	3.4212+02	3.5138+02	4.6076+02
15.0	6.6266+02	6.7555+02	8.2792+02
20.0	1.0099+03	1.0256+03	1.2122+03
25.0	1.3684+03	1.3860+03	1.6010+03
50.0	3.1495+03	3.1789+03	3.4850+03
75.0	4.7758+03	4.8221+03	5.1787+03
100.0	6.2256+03	6.2903+03	6.6798+03
125.0	7.5223+03	7.6050+03	8.0178+03
150.0	8.6918+03	8.7911+03	9.2214+03
175.0	9.7553+03	9.8698+03	1.0314+04
200.0	1.0730+04	1.0858+04	1.1313+04
225.0	1.1630+04	1.1770+04	1.2234+04
250.0	1.2465+04	1.2616+04	1.3088+04
275.0	1.3244+04	1.3405+04	1.3883+04
300.0	1.3974+04	1.4144+04	1.4628+04
325.0	1.4662+04	1.4840+04	1.5329+04
350.0	1.5311+04	1.5496+04	1.5990+04

Table III:Correction term for triplet production (formula 36) as extracted from reference [26].

TRIPLET CORRECTION TERM DELTA/Z

E (MEV)	DELTA/Z (MB)
9.0	-1.5000-03
10.0	3.0000-03
15.0	1.8000-02
20.0	2.6600-02
25.0	3.1200-02
50.0	3.5600-02
75.0	3.2636-02
100.0	2.9800-02
125.0	2.7587-02
150.0	2.5700-02
175.0	2.4178-02
200.0	2.2900-02
225.0	2.1738-02
250.0	2.0700-02
275.0	1.9809-02
300.0	1.9000-02
325.0	1.8213-02
350.0	1.7500-02

Table IV: Retardation factor for triplet pair production (formula 40).

RETARDATION FACTOR

E/MEV	FACTOR
9.0	.5156
10.0	.5485
15.0	.6564
20.0	.7179
25.0	.7583
50.0	.8513
75.0	.8885
100.0	.9093
125.0	.9229
150.0	.9325
175.0	.9398
200.0	.9455
225.0	.9501
250.0	.9538
275.0	.9570
300.0	.9598
325.0	.9621
350.0	.9642

Table V: Screening cross sections for triplet production.

TRIPLET SCREENING
(E IN MEV,CROSS SECTIONS IN MBARN)

E	Z= 3	Z= 4	Z= 6	Z= 8	Z=13
9.0	8.7396-07	7.1117-06	9.6706-05	5.7588-04	7.8181-03
10.0	2.3531-06	1.6442-05	1.8419-04	1.0489-03	1.2530-02
15.0	4.6844-05	2.4868-04	1.8548-03	8.0172-03	5.8330-02
20.0	2.6394-04	1.2434-03	7.4737-03	2.6017-02	1.3875-01
25.0	8.8867-04	3.7461-03	1.8973-02	5.6431-02	2.4613-01
50.0	1.9180-02	5.4451-02	1.6623-01	3.4143-01	1.0201+00
75.0	7.2284-02	1.6616-01	4.0383-01	7.3219-01	1.9967+00
100.0	1.5514-01	3.1399-01	6.7787-01	1.1643+00	3.0448+00
125.0	2.5760-01	4.7912-01	9.6783-01	1.6162+00	4.1019+00
150.0	3.7167-01	6.5146-01	1.2650+00	2.0771+00	5.1388+00
175.0	4.9205-01	8.2589-01	1.5648+00	2.5401+00	6.1429+00
200.0	6.1528-01	9.9982-01	1.8642+00	3.0007+00	7.1098+00
225.0	7.3919-01	1.1719+00	2.1615+00	3.4560+00	8.0381+00
250.0	8.6247-01	1.3415+00	2.4554+00	3.9040+00	8.9296+00
275.0	9.8428-01	1.5082+00	2.7451+00	4.3435+00	9.7856+00
300.0	1.1042+00	1.6718+00	3.0298+00	4.7736+00	1.0608+01
325.0	1.2219+00	1.8325+00	3.3096+00	5.1947+00	1.1401+01
350.0	1.3372+00	1.9900+00	3.5839+00	5.6056+00	1.2163+01

TRIPLET SCREENING
(E IN MEV,CROSS SECTIONS IN MBARN)

E	Z=20	Z=29	Z=50	Z=73	Z=82
9.0	4.8475-02	1.6345-01	7.0793-01	1.7318+00	2.2653+00
10.0	6.9641-02	2.1953-01	9.0420-01	2.1679+00	2.8191+00
15.0	2.2772-01	5.9168-01	2.1154+00	4.7199+00	6.0272+00
20.0	4.5391-01	1.0793+00	3.5840+00	7.6529+00	9.6762+00
25.0	7.2970-01	1.6455+00	5.1957+00	1.0779+01	1.3527+01
50.0	2.4967+00	5.0182+00	1.3816+01	2.6793+01	3.2800+01
75.0	4.4641+00	8.6356+00	2.2153+01	4.1575+01	5.0241+01
100.0	6.4167+00	1.2178+01	2.9846+01	5.4809+01	6.5724+01
125.0	8.2993+00	1.5555+01	3.6903+01	6.6702+01	7.9568+01
150.0	1.0097+01	1.8748+01	4.3395+01	7.7483+01	9.2072+01
175.0	1.1810+01	2.1761+01	4.9397+01	8.7337+01	1.0347+02
200.0	1.3440+01	2.4606+01	5.4976+01	9.6415+01	1.1394+02
225.0	1.4994+01	2.7296+01	6.0185+01	1.0483+02	1.2363+02
250.0	1.6476+01	2.9847+01	6.5074+01	1.1268+02	1.3266+02
275.0	1.7892+01	3.2269+01	6.9676+01	1.2002+02	1.4109+02
300.0	1.9248+01	3.4577+01	7.4028+01	1.2694+02	1.4903+02
325.0	2.0549+01	3.6781+01	7.8161+01	1.3348+02	1.5652+02
350.0	2.1797+01	3.8886+01	8.2086+01	1.3967+02	1.6361+02

Table VI: Experimental total absorption cross sections, $\sigma_{tot}(k)$ for Pb, Ta, Sn, and Cu. The third column (DS) gives the statistical errors.

Z=82

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
9.62	17035.24	28.16	19.62	21368.45	31.07
9.88	17167.06	21.49	19.88	21447.14	31.55
10.13	17348.50	18.26	20.13	21480.79	32.17
10.37	17462.61	16.73	20.38	21554.13	34.67
10.61	17620.76	16.48	20.62	21638.46	39.43
10.87	17807.38	16.79	20.87	21676.86	37.75
11.12	17940.21	19.74	21.13	21761.93	41.04
11.35	18150.23	23.79	21.36	21946.40	37.65
11.59	18316.33	25.10	21.60	21922.56	34.00
11.86	18376.78	30.18	21.82	22028.53	32.06
12.10	18557.69	27.15	22.06	22111.65	28.13
12.35	18731.43	25.10	22.29	22178.52	26.90
12.60	18867.24	20.99	22.56	22262.80	26.13
12.86	19031.40	22.42	22.83	22331.21	26.25
13.11	19184.27	21.98	23.10	22430.14	26.48
13.37	19402.00	24.08	23.37	22466.54	27.10
13.62	19555.66	25.08	23.64	22566.52	26.66
13.86	19646.39	25.52	23.90	22694.60	33.72
14.13	19757.25	25.17	24.13	22743.21	37.16
14.40	19826.21	26.22	24.38	22819.17	39.57
14.64	19873.02	25.30	24.63	22945.30	49.32
14.88	19934.12	26.88	24.85	22941.18	64.24
15.12	19974.38	28.95	25.13	23006.52	51.07
15.37	20027.40	30.11	25.38	23098.69	64.84
15.61	20089.94	31.40	25.62	23162.52	56.27
15.85	20120.55	31.21	25.80	23223.67	76.04
16.11	20217.35	29.77	26.08	23346.19	52.75
16.36	20237.52	30.76	26.31	23468.74	70.31
16.62	20367.11	28.89	26.57	23399.96	59.55
16.88	20445.24	28.23	26.82	23424.38	64.67
17.12	20583.90	30.72	27.08	23599.21	59.43
17.36	20579.58	27.60	27.35	23655.65	60.31
17.61	20677.25	28.16	27.59	23744.03	61.64
17.88	20783.69	26.57	27.86	23691.15	57.84
18.14	20849.55	28.34	28.10	23799.96	60.87
18.39	20918.24	28.08	28.37	23896.50	57.82
18.63	21094.97	30.45	28.61	24021.16	63.87
18.87	21111.68	29.13	28.88	24060.18	57.35
19.12	21213.37	29.88	29.10	24025.09	61.73
19.37	21229.78	30.16	29.37	24185.25	54.56

Table VI: Continued

Z=82

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
29.61	24238.80	54.62	49.81	27637.99	76.48
29.89	24249.07	52.29	50.33	27755.96	83.25
30.80	24480.38	42.58	50.81	27991.06	78.15
31.26	24576.75	40.53	51.36	28091.07	90.68
31.77	24716.60	43.30	51.83	28097.17	80.89
32.27	24830.00	45.60	52.35	28069.77	87.88
32.77	24913.95	46.98	52.82	28254.88	79.18
33.24	25039.82	45.67	53.38	28274.95	94.68
33.74	25193.36	46.92	53.86	28432.33	85.02
34.26	25177.63	48.30	54.40	28452.14	91.04
34.78	25349.00	50.95	54.85	28469.55	91.67
35.28	25379.92	50.04	55.26	28652.65	100.79
35.77	25468.66	49.37	55.74	28570.13	90.09
36.27	25703.01	50.94	56.16	28542.16	113.46
36.72	25729.62	58.67	56.65	28699.42	99.79
37.21	25774.24	52.71	57.06	28685.87	117.13
37.72	25878.35	53.76	57.57	28728.54	98.96
38.23	25923.63	56.71	58.13	28688.40	100.46
38.73	26061.46	59.66	58.65	28997.04	98.11
39.23	26171.70	60.61	59.23	28964.95	99.06
39.75	26225.88	59.69	59.70	29028.59	120.81
40.21	26299.95	60.44	60.26	29014.84	95.79
40.70	26394.28	65.87	60.67	29225.05	161.75
41.19	26572.70	58.36	61.21	29221.93	115.88
41.76	26592.19	62.65	61.71	29189.68	120.79
42.23	26607.18	58.46	62.27	29315.32	91.93
42.76	26807.97	61.84	62.79	29354.77	115.46
43.26	26823.80	59.71	63.28	29398.09	88.51
43.78	26986.02	70.45	63.81	29551.55	115.98
44.24	26905.21	56.21	64.27	29488.13	104.52
44.82	27039.40	61.66	64.67	29692.39	124.70
45.33	27161.42	69.30	65.23	29460.57	99.02
45.84	27241.60	63.75	65.73	29669.35	132.80
46.36	27213.83	71.20	66.20	29641.46	116.46
46.83	27401.96	74.99	66.74	29790.11	119.66
47.30	27421.93	72.47	67.26	29742.11	112.28
47.81	27469.57	69.44	67.79	29990.75	119.01
48.29	27563.86	71.40	68.18	29814.85	120.20
48.77	27607.62	68.74	68.76	30107.27	110.83
49.33	27739.68	81.26	69.30	30111.96	116.89

Table VI: Continued

Z=82

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
69.80	29932.23	145.24	104.44	32448.50	67.21
70.20	30028.44	128.38	105.48	32539.56	74.14
70.79	29989.44	128.63	106.47	32693.27	78.72
71.27	30150.97	145.75	107.52	32477.33	80.25
71.74	30133.39	129.42	108.62	32601.86	96.06
72.15	30363.21	131.58	109.68	32546.73	95.73
72.79	30403.61	113.93	110.68	32873.98	96.13
73.35	30310.95	134.37	111.67	32798.59	91.00
73.74	30488.40	138.98	112.76	32925.77	103.57
74.22	30493.40	111.84	113.62	32993.55	102.30
74.79	30495.83	133.56	114.53	32936.16	112.52
75.51	30421.48	83.68	115.45	33023.98	102.97
76.63	30512.45	76.48	116.31	32868.08	109.90
77.65	30807.48	74.60	117.35	33048.40	96.31
78.54	30635.72	76.53	118.27	33004.34	121.12
79.49	30835.23	73.91	119.24	33103.05	109.77
80.50	30976.13	74.94	120.42	33155.73	109.70
81.54	30817.12	67.51	121.52	33178.06	109.71
82.57	31077.08	74.67	122.49	33506.95	123.29
83.53	31110.96	77.20	123.43	33242.95	133.62
84.51	31166.96	70.62	124.55	33382.55	108.83
85.56	31368.52	80.05	126.04	33330.15	106.13
86.56	31346.65	87.00	128.01	33466.31	91.73
87.49	31240.86	78.39	130.16	33596.20	96.28
88.48	31448.81	76.02	131.93	33615.18	106.32
89.47	31476.94	78.06	133.95	33836.13	85.91
90.51	31509.08	78.17	136.07	33723.34	82.12
91.50	31625.05	79.05	137.89	33853.77	91.50
92.45	31766.04	77.18	139.91	33968.16	74.22
93.48	31878.88	75.10	142.06	34037.52	70.13
94.54	31779.30	75.68	144.10	34153.09	78.33
95.51	31814.27	73.45	145.80	34220.63	75.46
96.49	31866.57	62.96	147.88	34155.45	60.87
97.51	31981.91	65.11	150.04	34294.88	74.80
98.42	32026.14	69.88	151.89	34310.18	68.04
99.40	32059.83	62.85	154.02	34297.59	62.63
100.44	32147.12	65.10	156.16	34367.75	87.47
101.39	32265.05	68.43	157.62	34508.77	87.04
102.40	32325.19	65.26	159.82	34392.88	75.60
103.45	32288.19	70.37	161.92	34631.98	97.44

Table VI: Continued

Z=73

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
9.61	14182.12	23.11	32.70	20422.18	75.68
9.86	14239.85	20.75	33.07	20294.15	93.61
10.11	14389.38	22.84	37.24	21135.43	129.35
10.36	14490.66	22.08	37.69	21276.10	92.59
10.57	14572.65	36.11	38.21	21307.62	66.70
11.20	15005.63	51.97	38.72	21298.21	54.88
11.40	14977.59	32.95	39.20	21338.86	52.12
11.60	15031.24	25.57	39.72	21324.55	41.62
11.85	15191.29	26.38	40.24	21467.26	44.91
12.10	15341.68	28.89	40.75	21562.67	42.71
12.36	15449.29	25.07	41.23	21594.09	51.77
12.63	15538.74	41.93	41.70	21534.94	49.51
13.98	16095.20	165.46	42.20	21696.00	57.33
14.15	16214.61	46.39	42.72	21666.63	56.82
14.37	16235.02	30.75	43.28	21689.79	88.41
14.63	16379.05	27.36	43.70	21736.47	106.66
14.89	16420.43	28.50	46.91	22630.98	143.25
15.14	16584.16	30.65	47.40	22542.43	96.16
15.38	16646.88	29.41	47.90	22518.45	81.15
15.62	16743.98	33.54	48.39	22641.07	69.44
15.86	16843.68	41.84	48.89	22686.82	63.92
18.87	17446.02	38.30	49.38	22896.27	57.57
19.13	17506.94	30.88	49.89	22884.08	58.68
19.37	17628.50	27.05	50.39	22858.97	59.27
19.62	17665.66	32.43	50.88	22877.77	60.13
19.88	17710.12	27.31	51.37	22952.20	60.98
20.13	17774.59	33.83	51.85	23083.70	62.40
20.37	17790.54	27.77	52.35	23087.31	67.82
20.63	17897.47	32.82	52.85	23218.02	77.07
20.86	17947.34	32.74	53.36	23291.78	87.90
21.09	18051.78	50.31	53.87	23297.86	109.94
28.26	19541.25	50.98	54.36	23263.68	141.91
28.76	19731.41	47.11	70.67	25029.01	192.97
29.25	19758.89	40.64	71.24	24701.16	112.08
29.76	19909.19	36.77	71.82	24616.90	110.85
30.26	19920.77	31.69	72.22	24800.76	103.01
30.78	20016.76	36.91	72.77	24779.39	83.70
31.23	20079.52	42.10	73.32	24816.21	91.42
31.73	20127.94	43.81	73.74	24843.11	87.55
32.26	20300.81	51.70	74.28	24816.42	84.15

Z=73

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
74.83	24821.60	93.90	114.19	26650.24	161.12
75.25	25011.77	90.97	115.26	27194.10	120.18
75.55	24964.67	60.90	116.35	27045.71	100.49
76.52	25041.64	67.36	117.42	27153.67	85.43
77.47	25192.47	62.27	118.50	27055.06	92.90
78.50	25134.42	67.18	119.61	27118.48	97.45
79.49	25193.93	101.18	120.59	27236.57	102.56
80.28	25279.99	137.67	121.32	27245.28	115.59
81.09	25201.72	231.60	122.22	27260.79	88.08
93.56	25971.21	167.93	123.35	27294.14	84.74
94.56	26165.84	141.33	124.51	27265.12	85.59
95.55	26031.24	120.28	125.63	27403.58	90.42
96.54	26126.65	127.67	126.14	27418.40	67.03
97.53	26186.41	100.59	128.28	27539.47	91.36
98.51	26314.99	89.78	130.05	27077.83	298.58
99.52	26151.93	90.74	142.60	27652.44	218.73
100.51	26219.95	91.75	143.96	27787.88	113.08
101.45	26235.58	106.29	146.01	27784.96	74.00
102.45	26184.88	93.44	148.00	27967.68	66.11
103.41	26351.14	95.08	149.91	28062.68	66.56
104.46	26274.47	110.59	152.01	28079.59	58.51
105.47	26357.66	121.81	154.05	27984.40	64.53
106.48	26295.18	139.99	156.01	28151.12	59.94
107.49	26754.36	168.11	157.91	28177.97	64.30
108.48	26426.59	209.30	159.84	28156.05	73.97
113.12	26772.87	258.09	161.78	28299.57	93.14

Table VI: Continued

Z=50

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
9.62	7641.16	13.29	19.62	9248.39	24.28
9.87	7686.26	10.58	19.88	9275.08	21.66
10.13	7739.68	9.24	20.15	9290.24	24.67
10.37	7776.10	8.33	20.37	9361.30	29.10
10.61	7822.03	9.30	20.57	9397.59	35.84
10.87	7869.91	9.82	20.86	9392.06	23.15
11.12	7902.01	11.94	21.14	9421.00	38.62
11.36	7973.39	14.36	21.36	9418.11	39.23
11.58	8027.71	17.50	21.57	9483.61	40.04
11.86	8060.46	15.07	21.80	9506.14	32.06
12.10	8090.52	20.51	22.07	9507.63	28.23
12.34	8167.52	16.89	22.36	9537.37	39.98
12.61	8210.26	17.08	22.64	9599.50	60.09
12.86	8278.51	19.01	22.79	9595.49	33.00
13.11	8325.14	17.49	23.08	9653.78	29.10
13.36	8401.78	19.59	23.37	9624.87	41.00
13.61	8438.15	17.82	23.65	9667.72	33.59
13.87	8485.51	19.87	23.83	9699.99	42.28
14.11	8555.38	18.24	24.05	9703.94	34.34
14.39	8617.06	18.56	24.33	9735.81	35.06
14.64	8662.33	20.48	24.64	9787.22	34.31
14.87	8757.31	20.66	24.90	9841.52	35.14
15.12	8784.58	19.34	25.15	9876.41	35.71
15.37	8799.68	20.99	25.28	9825.10	63.08
15.60	8859.93	22.00	25.56	9879.52	34.95
15.85	8913.11	20.39	25.83	9882.28	35.61
16.11	8896.44	22.86	26.12	9964.81	31.92
16.35	8928.07	21.52	26.30	9978.26	63.06
16.64	8974.03	20.72	26.56	9982.32	35.41
16.88	9012.77	24.41	26.83	10032.38	36.15
17.10	9043.06	31.47	27.10	10002.94	36.51
17.35	9078.16	24.53	27.37	10043.99	37.17
17.61	9078.09	24.14	27.57	10060.35	44.96
17.90	9098.46	22.29	27.83	10129.75	37.59
18.14	9090.70	27.59	28.11	10128.50	38.06
18.39	9143.67	21.06	28.39	10144.55	38.76
18.64	9156.02	26.66	28.56	10124.57	44.87
18.88	9178.55	20.61	28.84	10174.63	38.16
19.12	9229.36	21.16	29.13	10178.75	38.59
19.36	9219.48	21.29	29.42	10235.26	39.45

Z=50

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
29.58	10325.43	47.67	35.73	10676.72	90.97
29.85	10309.42	38.67	35.82	10720.30	89.94
30.15	10325.09	39.52	36.15	10811.99	91.36
30.45	10282.95	34.40	36.47	10924.47	95.59
30.68	10368.32	70.40	36.79	10842.60	96.50
30.85	10360.55	40.03	47.90	11498.38	67.05
31.12	10318.07	48.58	48.40	11648.85	69.40
31.39	10388.82	36.01	48.89	11599.95	55.61
31.61	10353.40	51.10	49.39	11603.97	56.92
31.86	10456.79	42.91	49.87	11652.46	49.33
32.11	10417.47	53.14	50.37	11631.12	50.85
32.38	10516.07	38.22	50.87	11667.46	51.14
32.62	10463.55	53.82	51.36	11608.54	52.32
32.78	10608.14	56.77	51.85	11726.63	53.75
33.08	10496.45	46.04	52.38	11678.44	61.83
33.39	10559.73	40.48	52.86	11725.86	62.51
33.60	10598.73	80.34	53.40	11746.72	77.56
33.77	10563.26	47.64	53.88	11748.81	78.59
34.10	10642.79	48.98	100.36	13351.11	53.03
34.43	10591.44	49.42	101.34	13428.12	53.78
34.66	10670.28	89.84	102.47	13472.50	48.55
34.79	10644.45	61.79	103.54	13507.29	55.60
35.12	10595.53	61.09	104.56	13346.47	50.55
35.45	10672.01	62.65	105.59	13498.12	56.33

Table VI: Continued

Z=29

E MEV	SIGMA MB	DS MB	E MEV	SIGMA MB	DS MB
9.62	3268.59	5.35	17.88	3622.49	6.97
9.87	3282.29	4.28	18.14	3617.74	9.36
10.13	3289.47	3.69	18.39	3643.18	7.21
10.37	3291.01	3.29	18.64	3658.73	9.73
10.61	3297.38	3.68	18.86	3641.75	8.83
10.86	3304.98	4.17	19.11	3662.35	10.09
11.12	3315.72	5.19	19.36	3682.49	10.16
11.34	3321.82	8.64	19.64	3681.92	12.07
11.50	3325.58	14.97	46.92	4289.62	24.69
14.17	3446.45	18.13	47.42	4272.67	25.05
14.40	3457.99	13.37	47.90	4341.23	20.66
14.64	3453.70	19.55	48.39	4274.83	20.93
14.86	3452.69	14.00	48.87	4346.82	18.15
15.14	3495.30	10.19	49.36	4302.36	18.46
15.37	3498.20	9.42	49.84	4324.70	16.57
15.60	3529.89	8.74	50.34	4325.04	16.78
15.87	3536.93	7.78	50.83	4383.17	17.26
16.10	3553.03	9.19	51.36	4367.16	19.32
16.35	3570.98	6.71	51.85	4365.92	19.72
16.64	3586.80	6.88	52.38	4374.17	22.79
16.87	3604.54	7.72	52.86	4381.60	22.93
17.11	3611.18	7.73	53.40	4399.66	28.48
17.36	3610.81	7.29	53.88	4385.71	28.51
17.61	3633.76	8.14			

Figure 1 Total photoabsorption cross sections, $\sigma_{tot}(k)$ [1]. The statistical errors of the experimental points are smaller than the plotted circles. The lines indicate the calculated atomic cross sections, $\sigma_a(k)$.

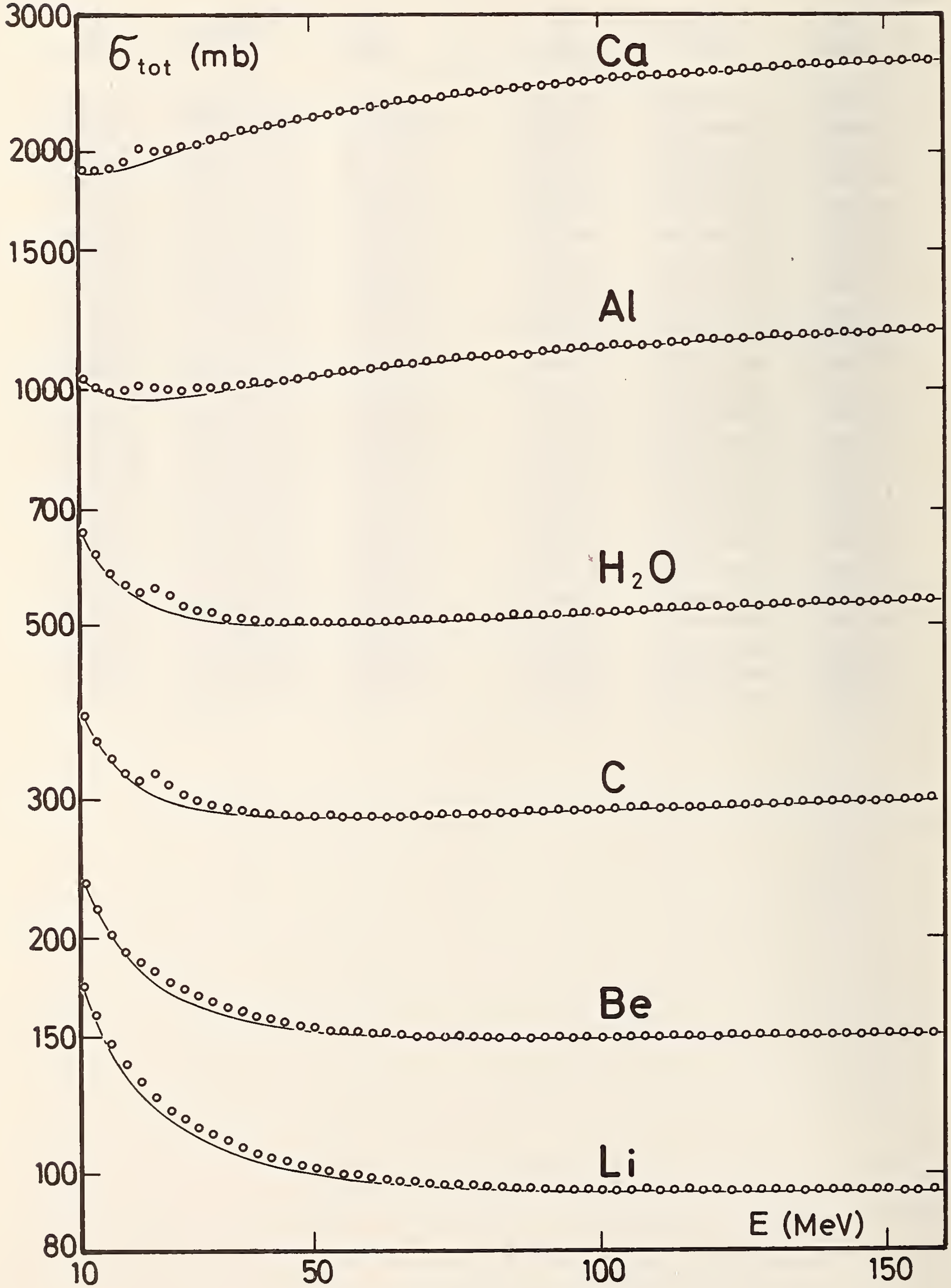


Figure 2 Calculated atomic cross sections, $\sigma_a(k)$, (circles) for Li. The partial cross sections for Compton effect, $\sigma_c(k)$, for pair production in the nuclear Coulomb field, $\sigma_p(k)$ and for pair production in the electron field, $\sigma_t(k)$, are also given. The atomic photoelectric cross section, $\sigma_{ph}(k)$, is too small to be displayed in this scale.

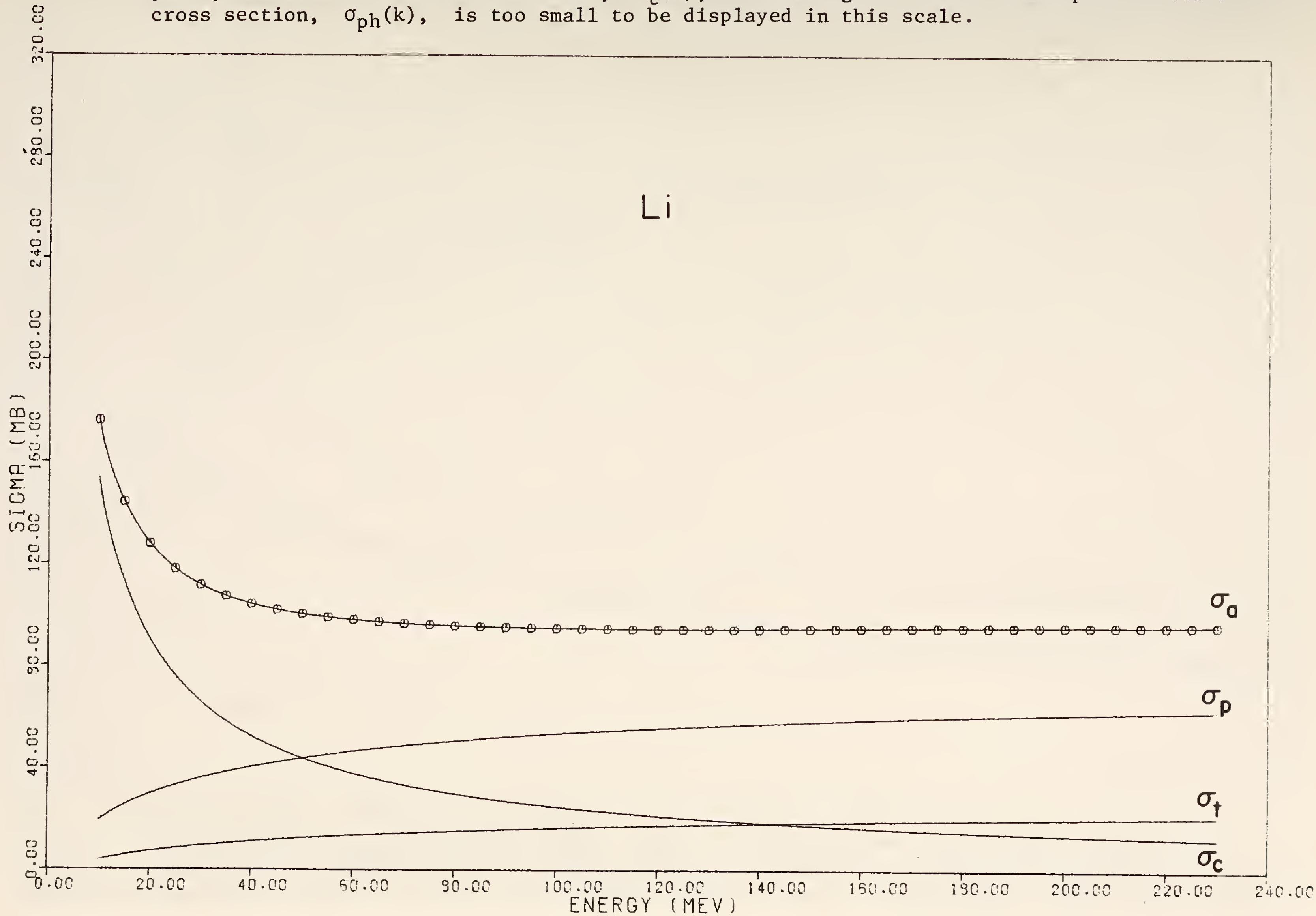


Figure 3 Calculated atomic cross sections, $\sigma_a(k)$, (circles) for Ca. The partial cross sections for Compton effect, $\sigma_c(k)$, for pair production in the nuclear Coulomb field, $\sigma_p(k)$ and for pair production in the electron field, $\sigma_t(k)$, are also given. The atomic photoelectric cross section, $\sigma_{ph}(k)$, is too small to be displayed in this scale.

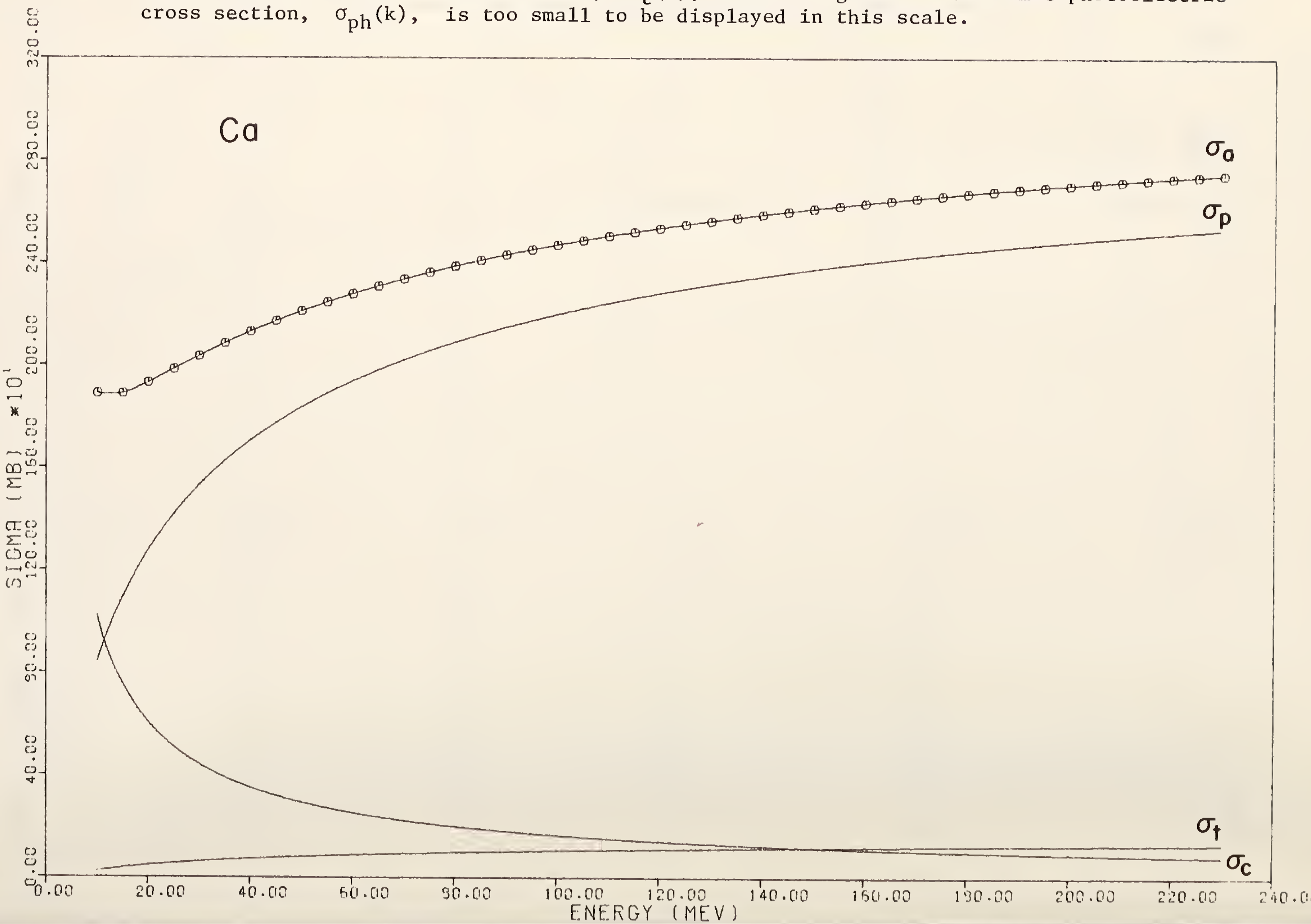


Figure 4 Calculated atomic cross sections, $\sigma_a(k)$, (circles) for Pb. The partial cross sections for Compton effect, $\sigma_c(k)$, for pair production in the nuclear Coulomb field, $\sigma_p(k)$ and for pair production in the electron field, $\sigma_t(k)$, are also given. The atomic photoelectric cross section, $\sigma_{ph}(k)$, is too small to be displayed in this scale.

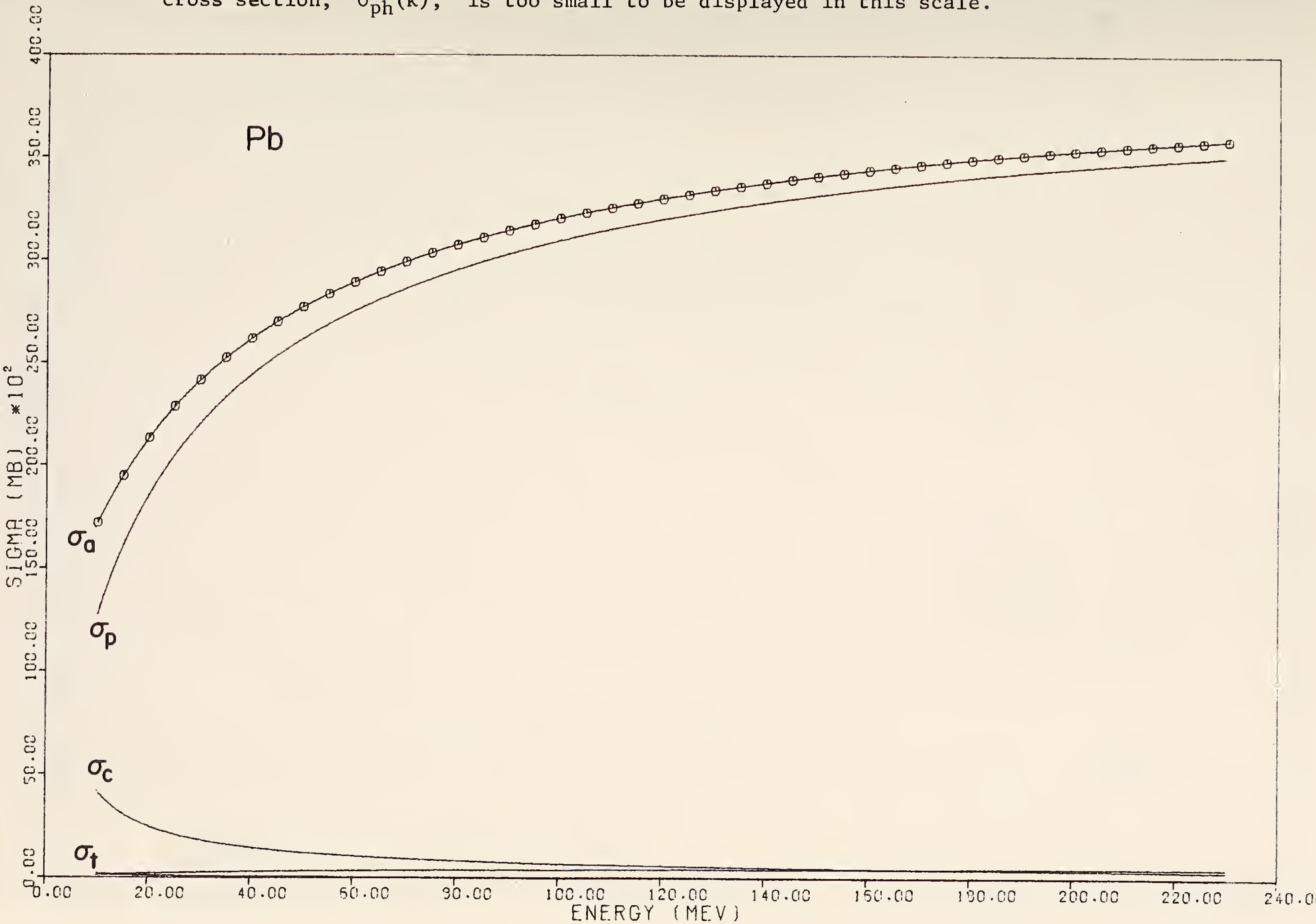


Figure 5 Screening corrections, ΔS, and Coulomb corrections, $\Delta Coul$, for pair production in the nuclear Coulomb field in units of the atomic absorption cross section, $\sigma_a(k)$, for different elements.

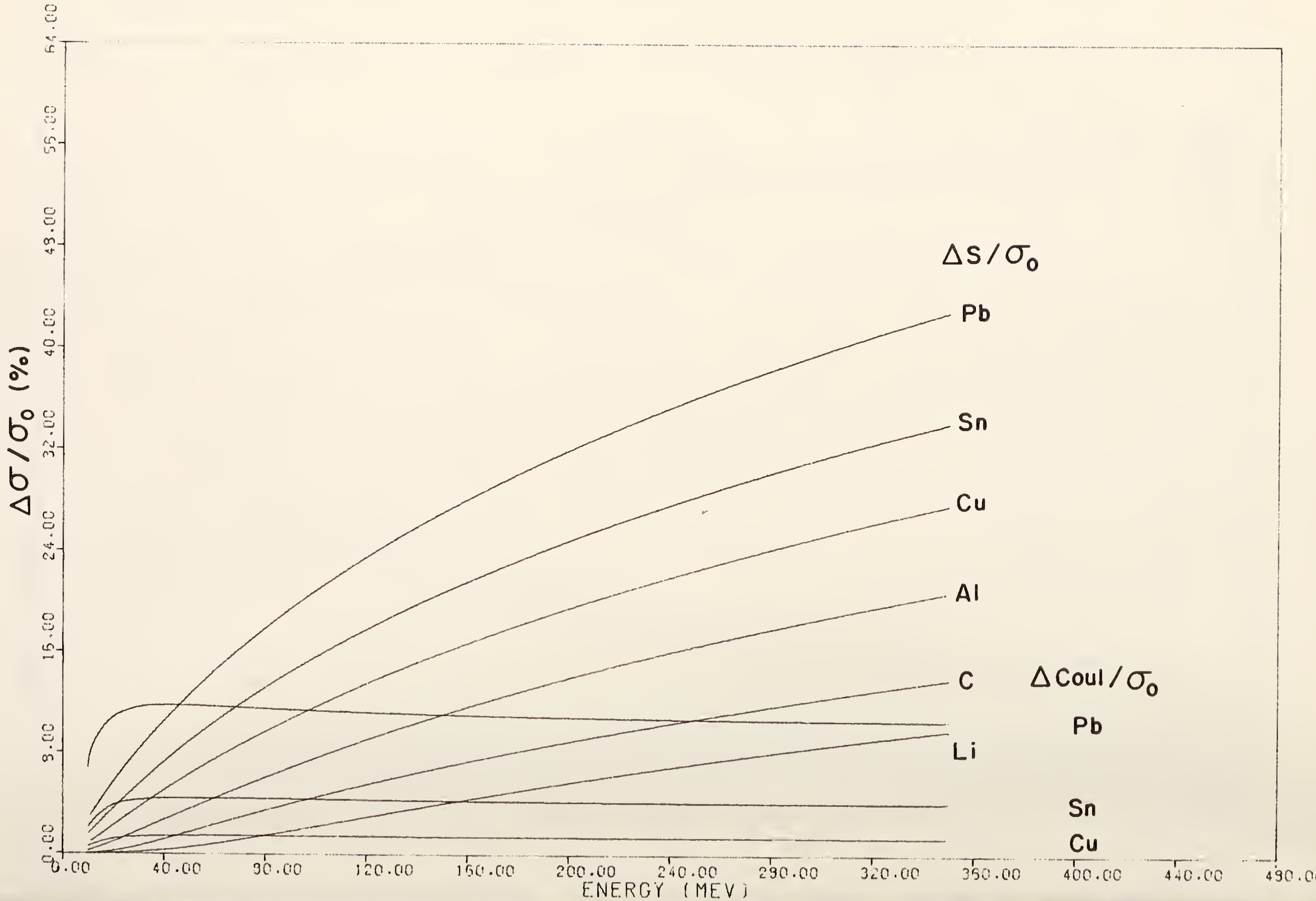


Figure 6 Coulomb correction cross section, ΔCoul, for pair production in the nuclear Coulomb field [12] for lead. The straight line (DBM) shows the energy independent value calculated by Davies, Bethe and Maximon [7].

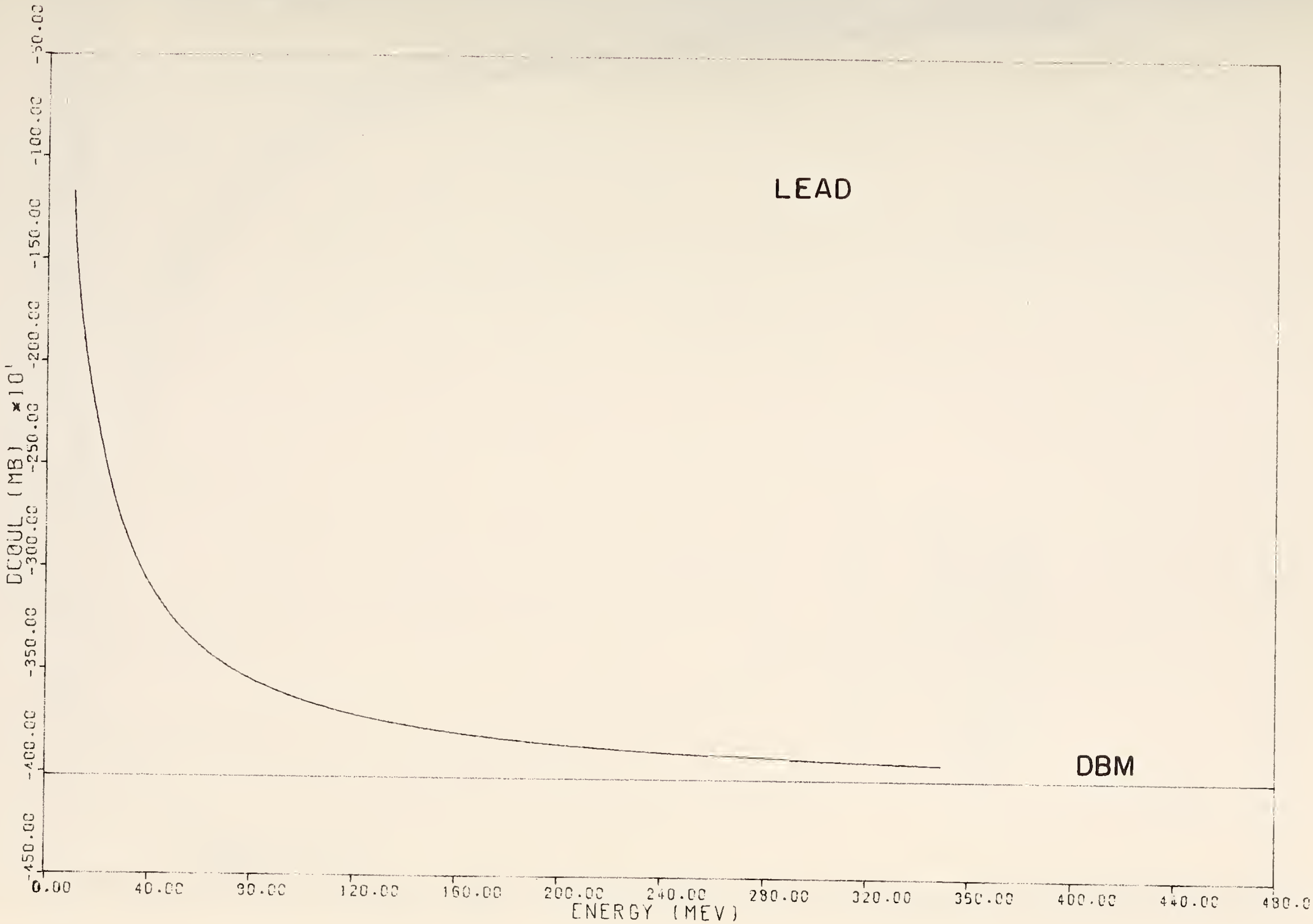


Figure 7 Recoil distribution, $\frac{d\sigma}{dq}(k,q)/Z^2$, for pair production in the nuclear Coulomb field [14] (formula (21)).

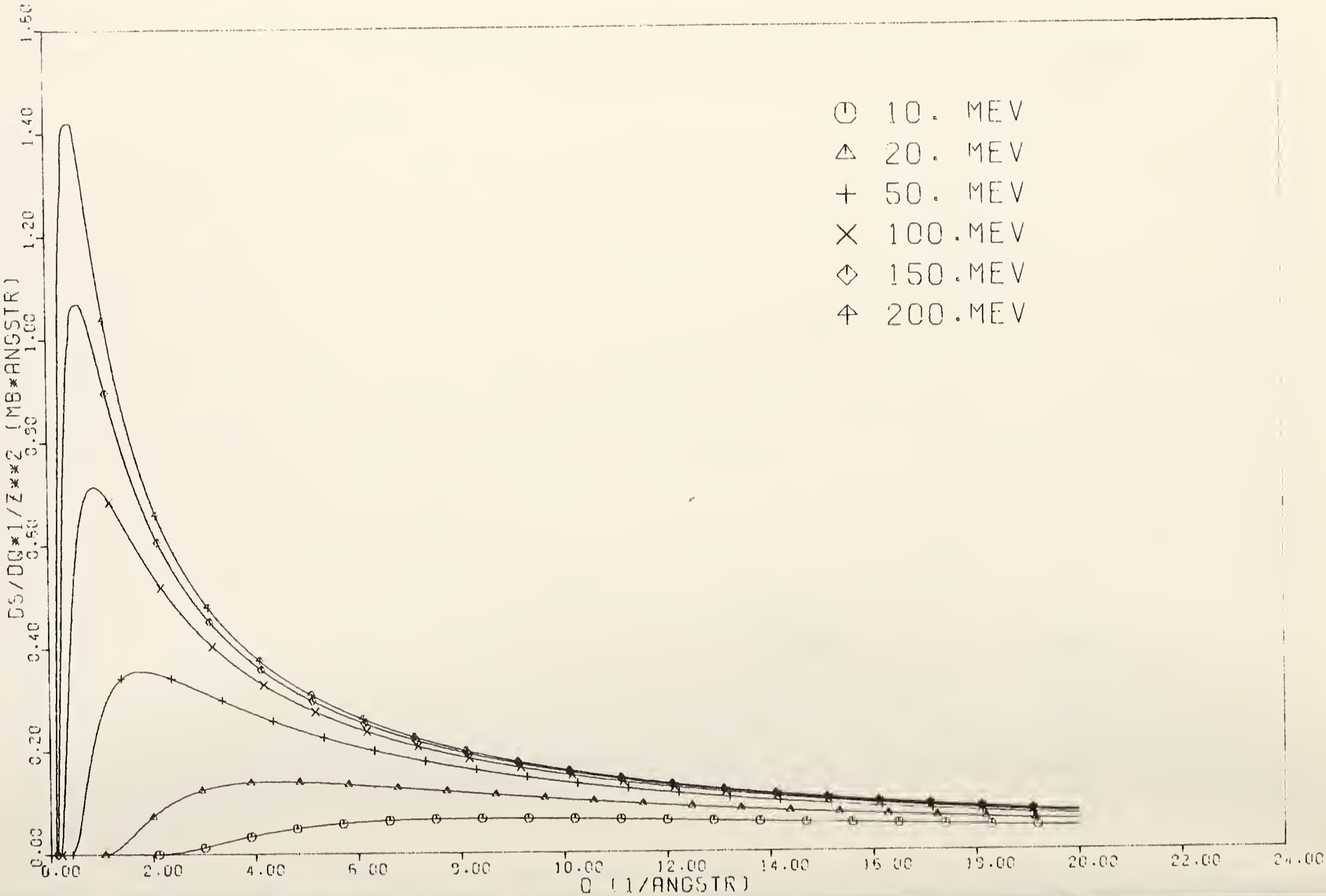


Figure 8 Difference between the screening correction for pair production in the nuclear field obtained with relativistic resp. nonrelativistic form factors in formula (20) and the screening correction obtained with Thomas-Fermi form factors in units of the atomic absorption cross section, $\sigma_a(k)$.

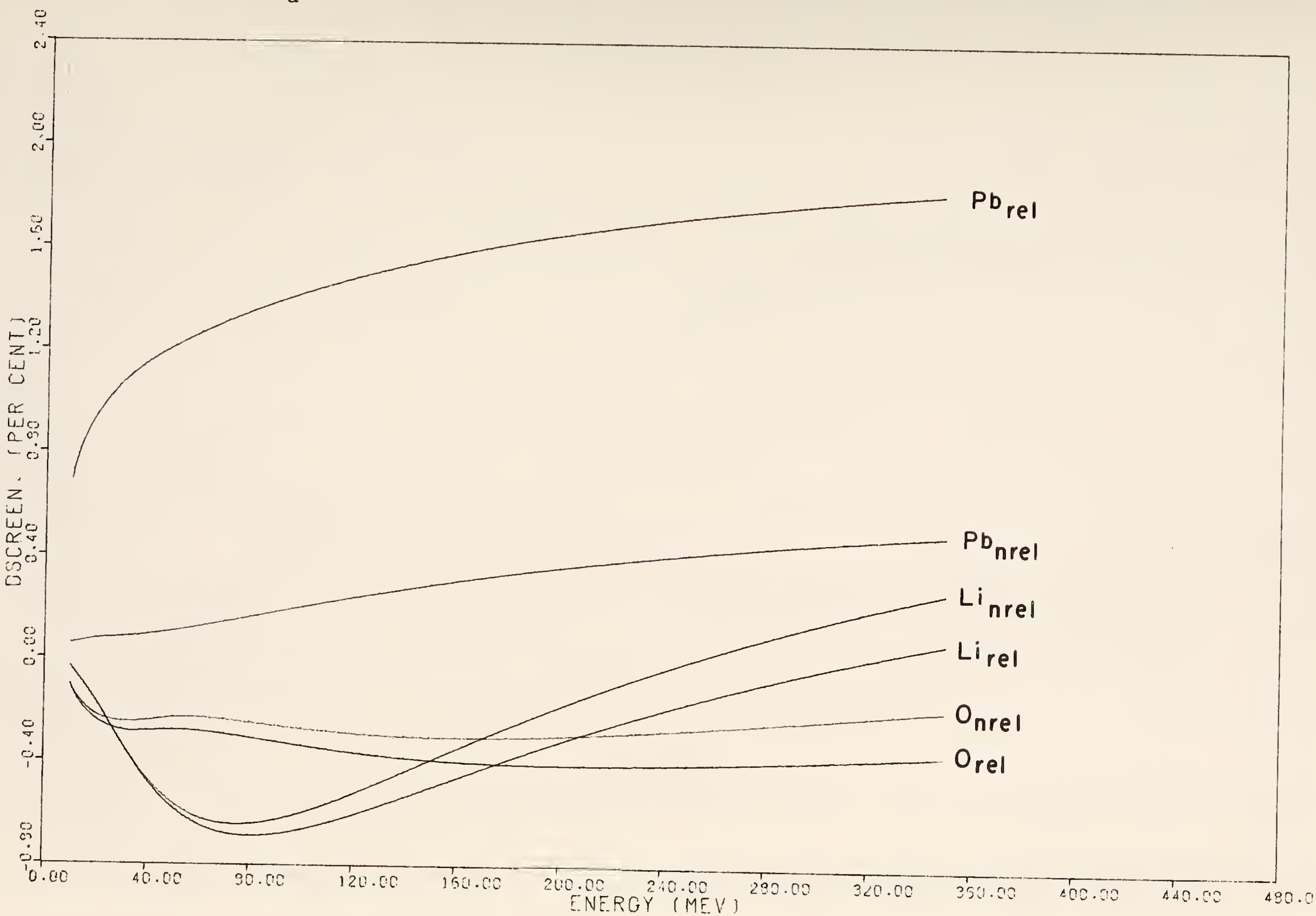


Figure 9 Retardation factor, f_{ret}, for triplet production derived from formula (40).

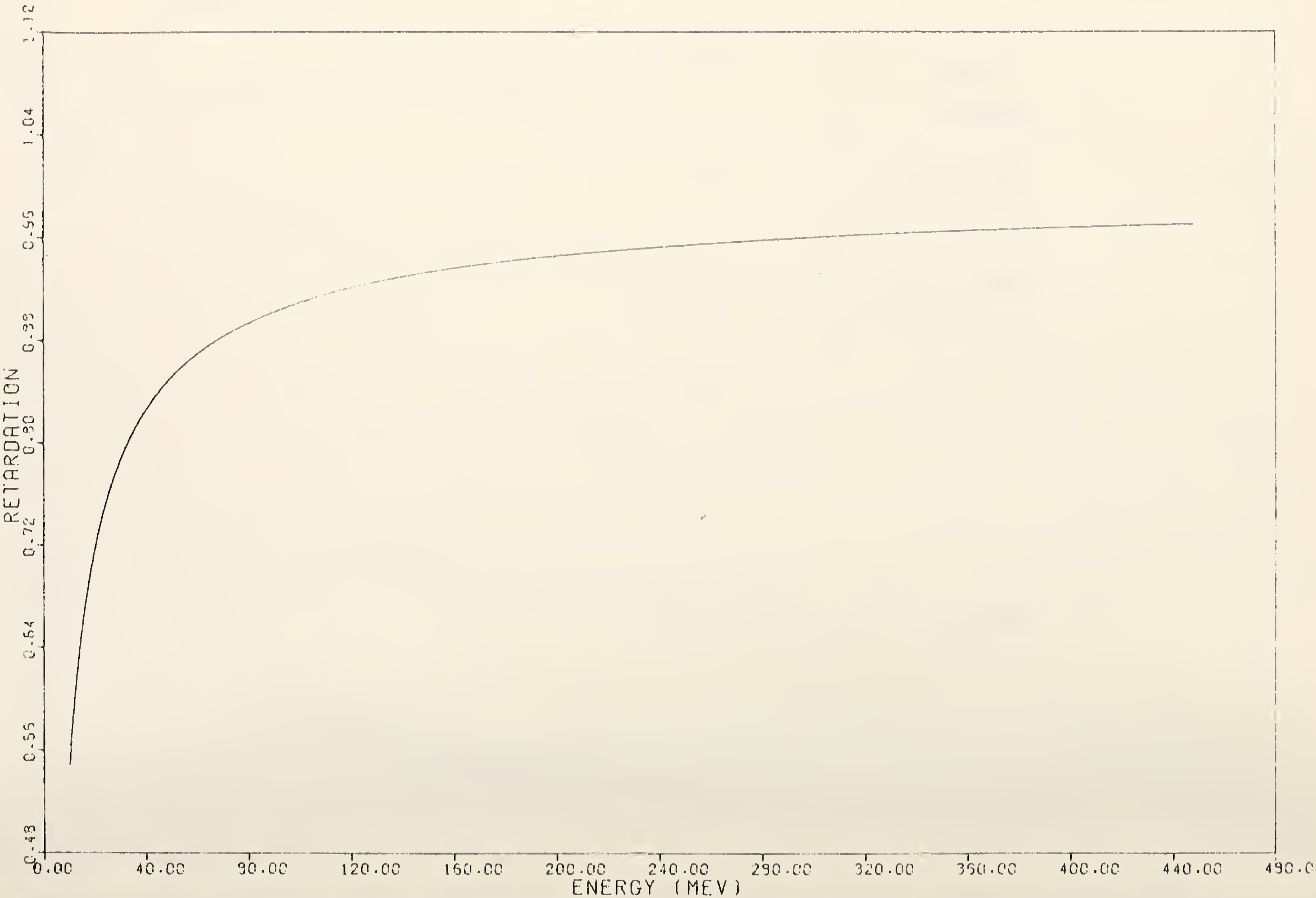


Figure 10 Screening correction, ΔS_t, for triplet production in units of the unscreened triplet cross section, $\sigma_o(k)$. The circles indicate the screening correction for lead if retardation is neglected.

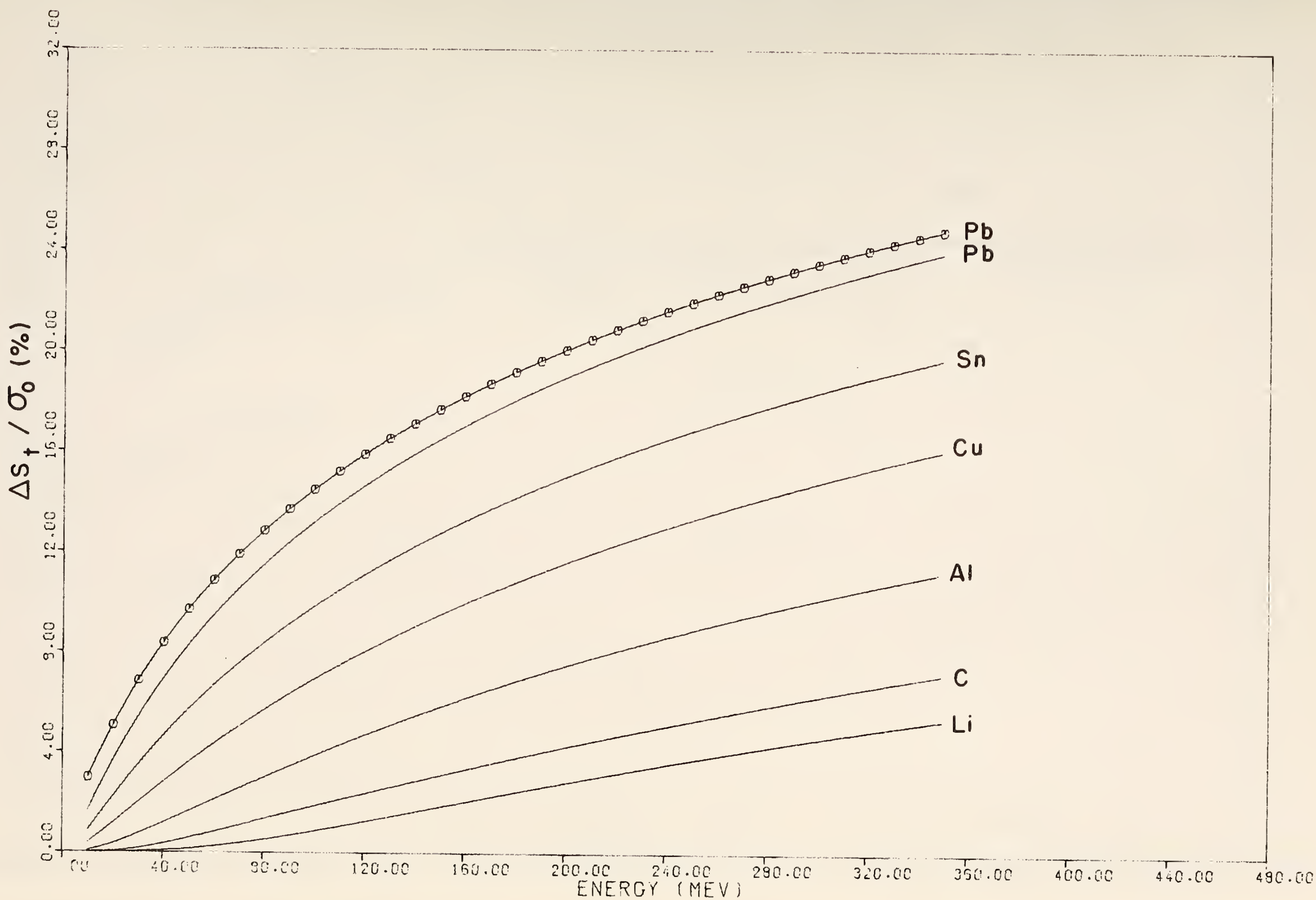


Figure 11 Screening correction, ΔS_t, for triplet production in units of the total atomic cross section, $\sigma_a(k)$.

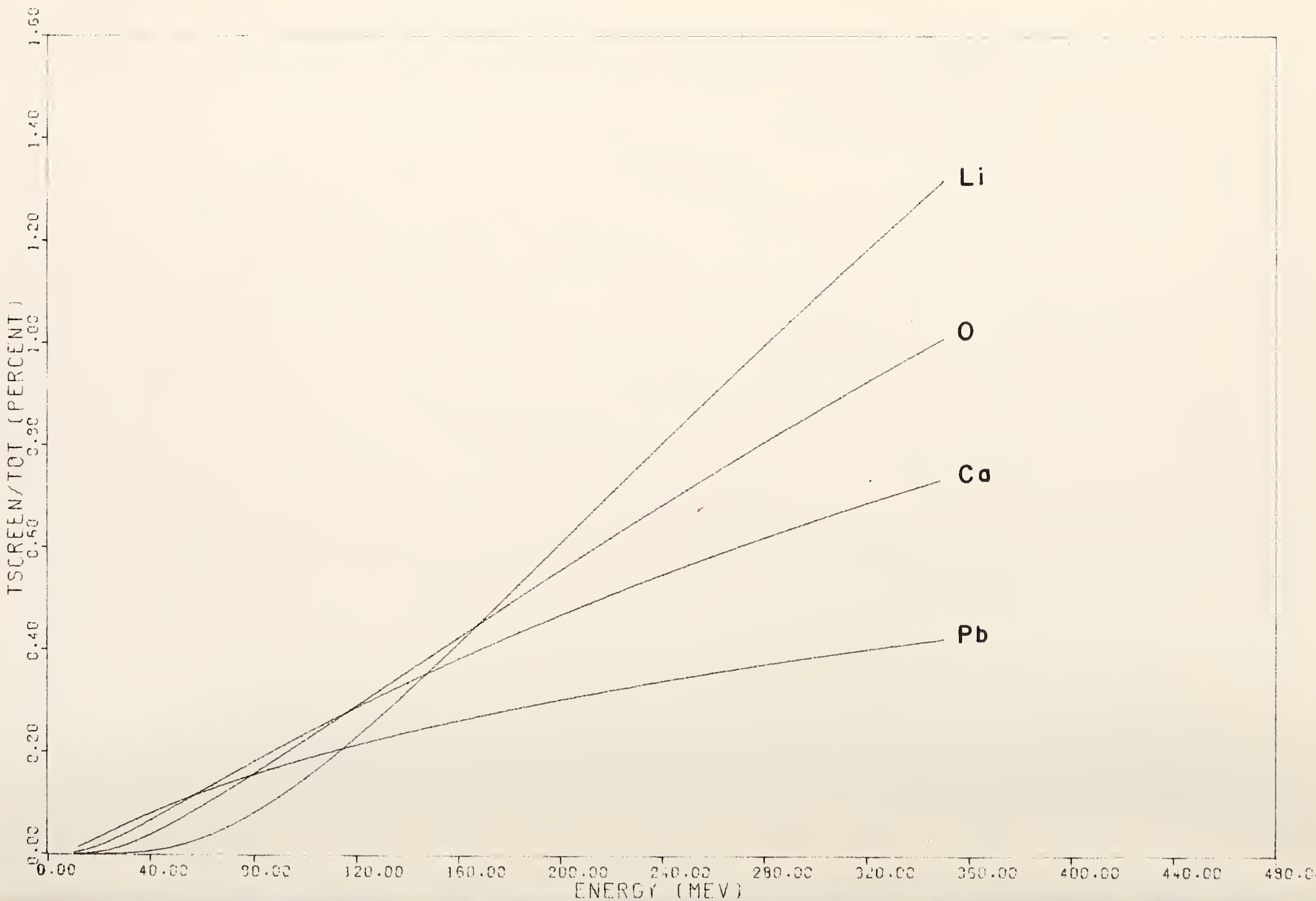


Figure 12 Measured total absorption cross sections, $\sigma_{tot}(k)$, for Cu, Sn, Ta and Pb. The statistical errors are smaller than the displayed points.

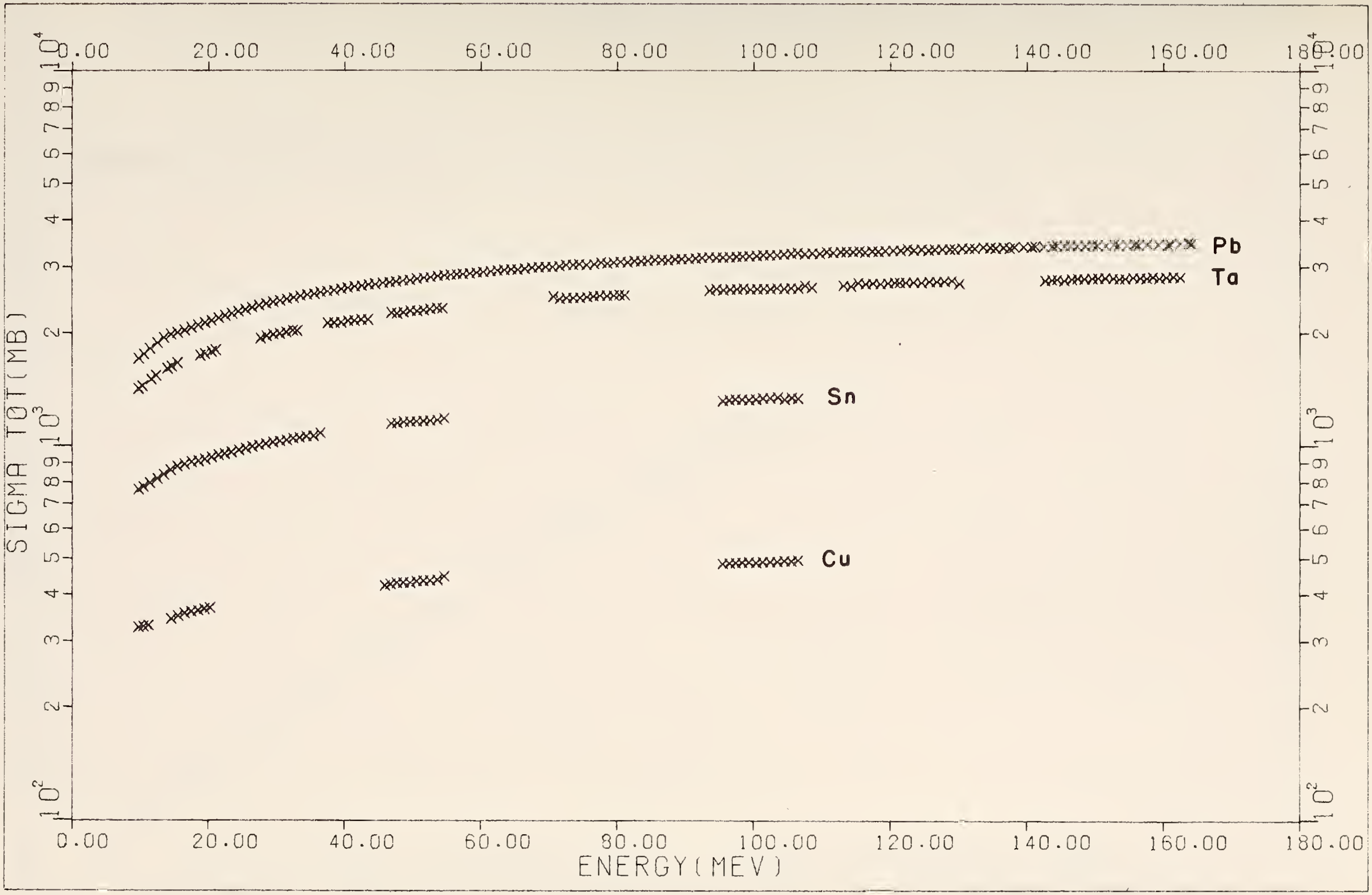


Figure 13 Difference of the screening correction for pair production in the nuclear Coulomb field obtained with relativistic form factors in equation (20) and the screening correction obtained with nonrelativistic form factors in units of the atomic cross section, $\sigma_a(k)$.

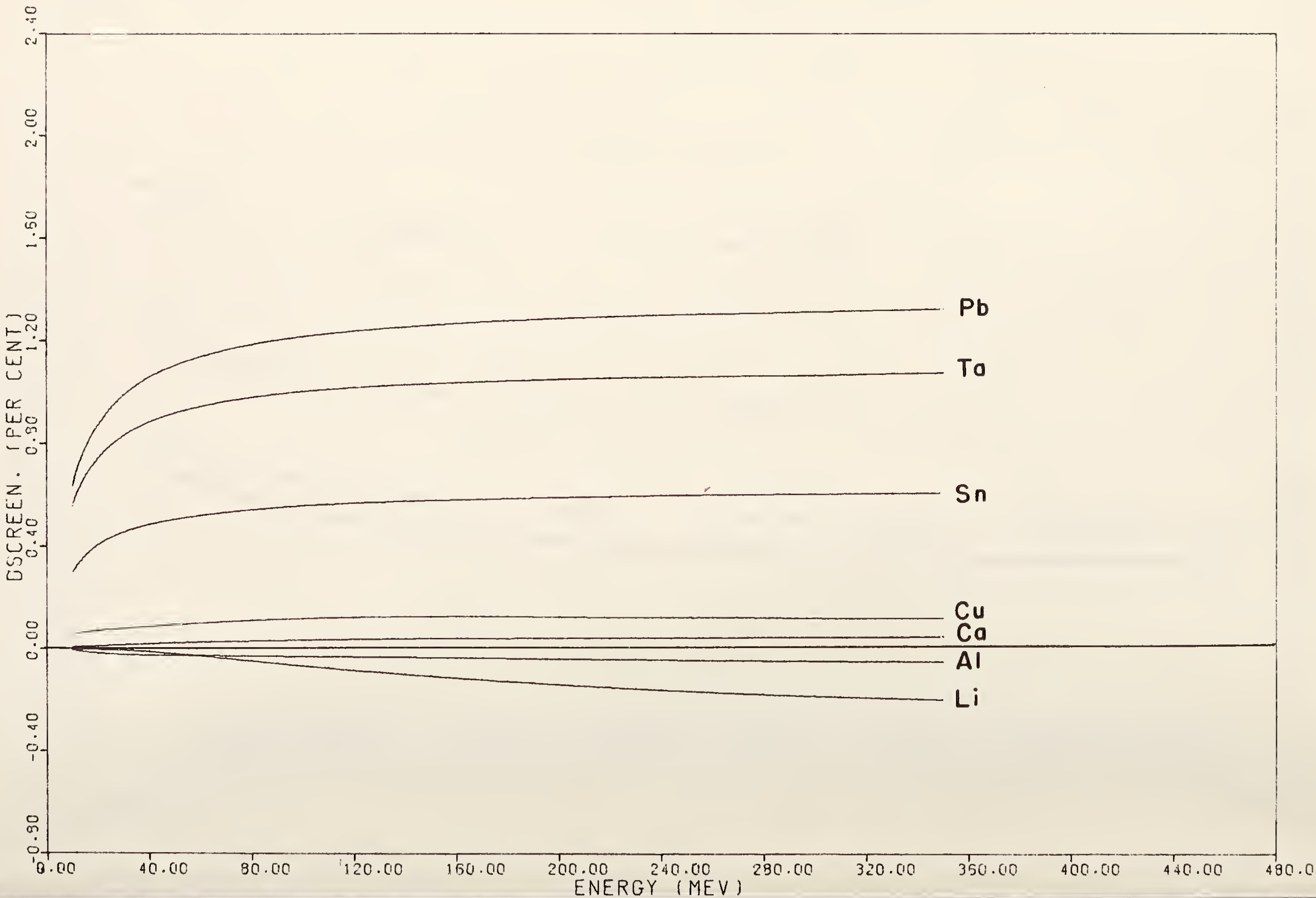


Figure 14 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for lead (derived from equation (42)). The curve gives the calculated screening correction obtained with nonrelativistic form factors in formula (20). The error bars display the statistical errors of the experimental data. The structure in the low energy part of the plot reflects the nuclear giant resonance.

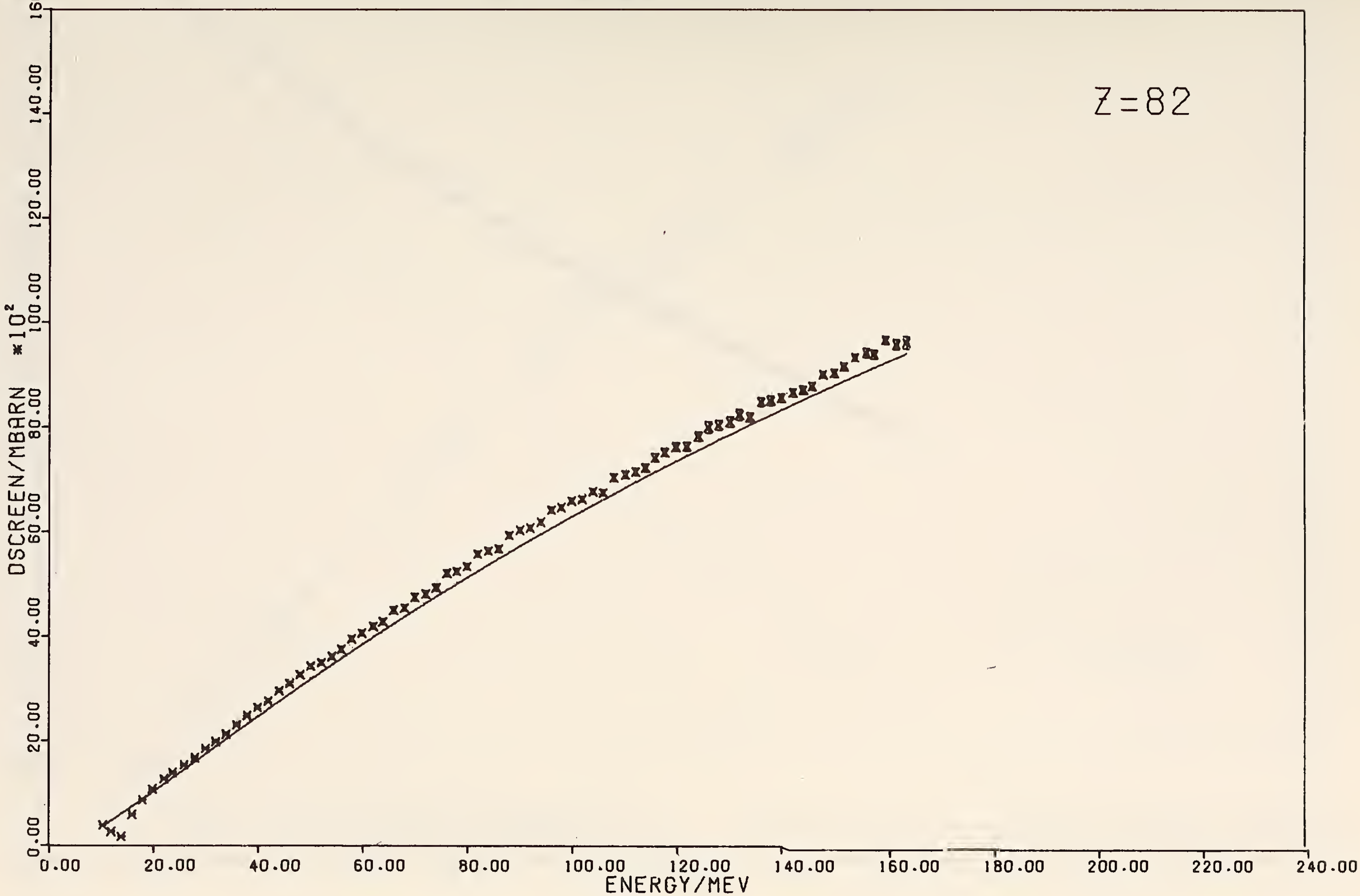


Figure 15 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for lead (derived from equation (42)). The curve gives the calculated screening correction obtained with relativistic form factors.

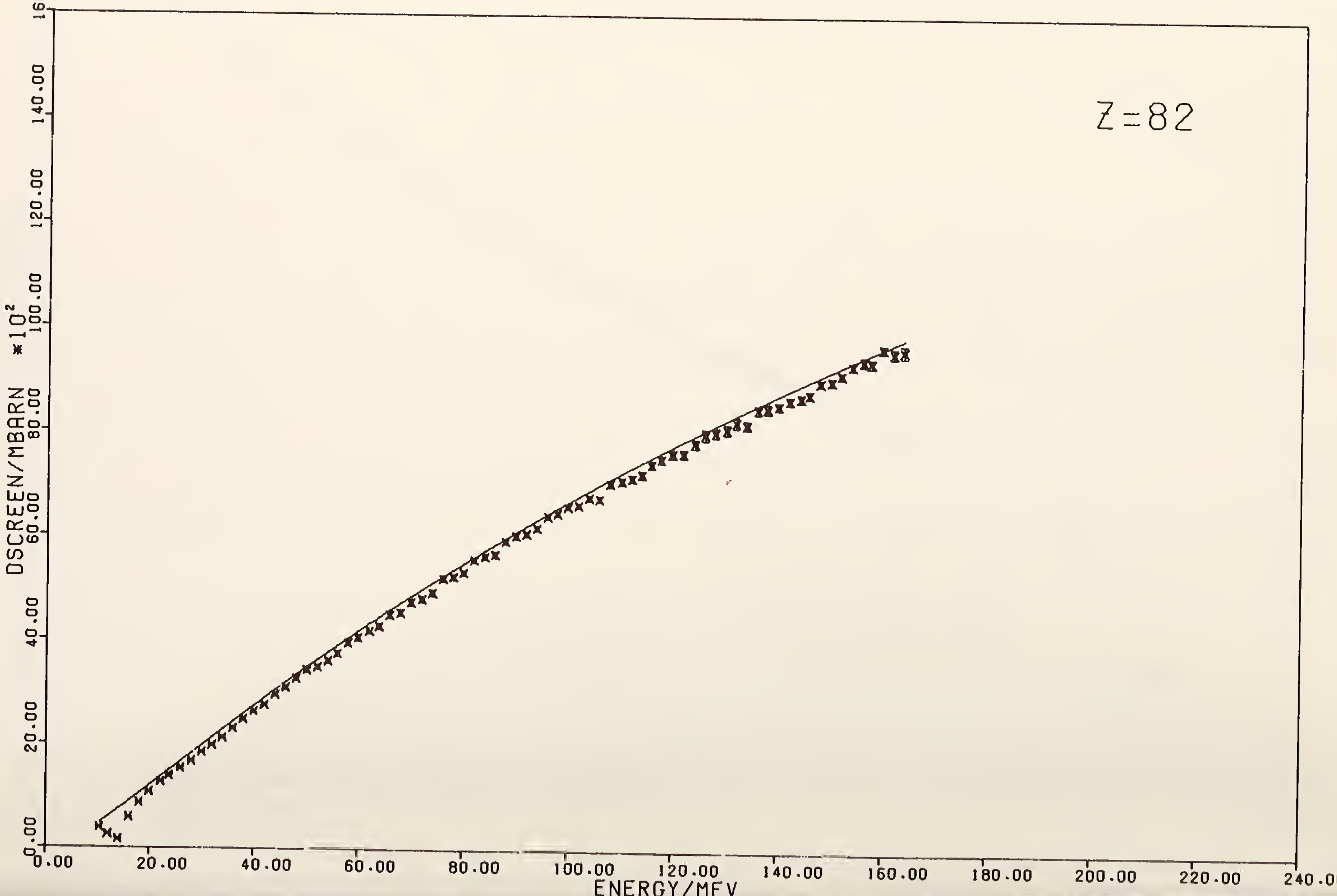


Figure 16 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for tantalum (derived from equation (42)). The curve gives the calculated screening correction obtained with nonrelativistic form factors in formula (20). The error bars display the statistical errors of the experimental data. The structure in the low energy part of the plot reflects the nuclear giant resonance.

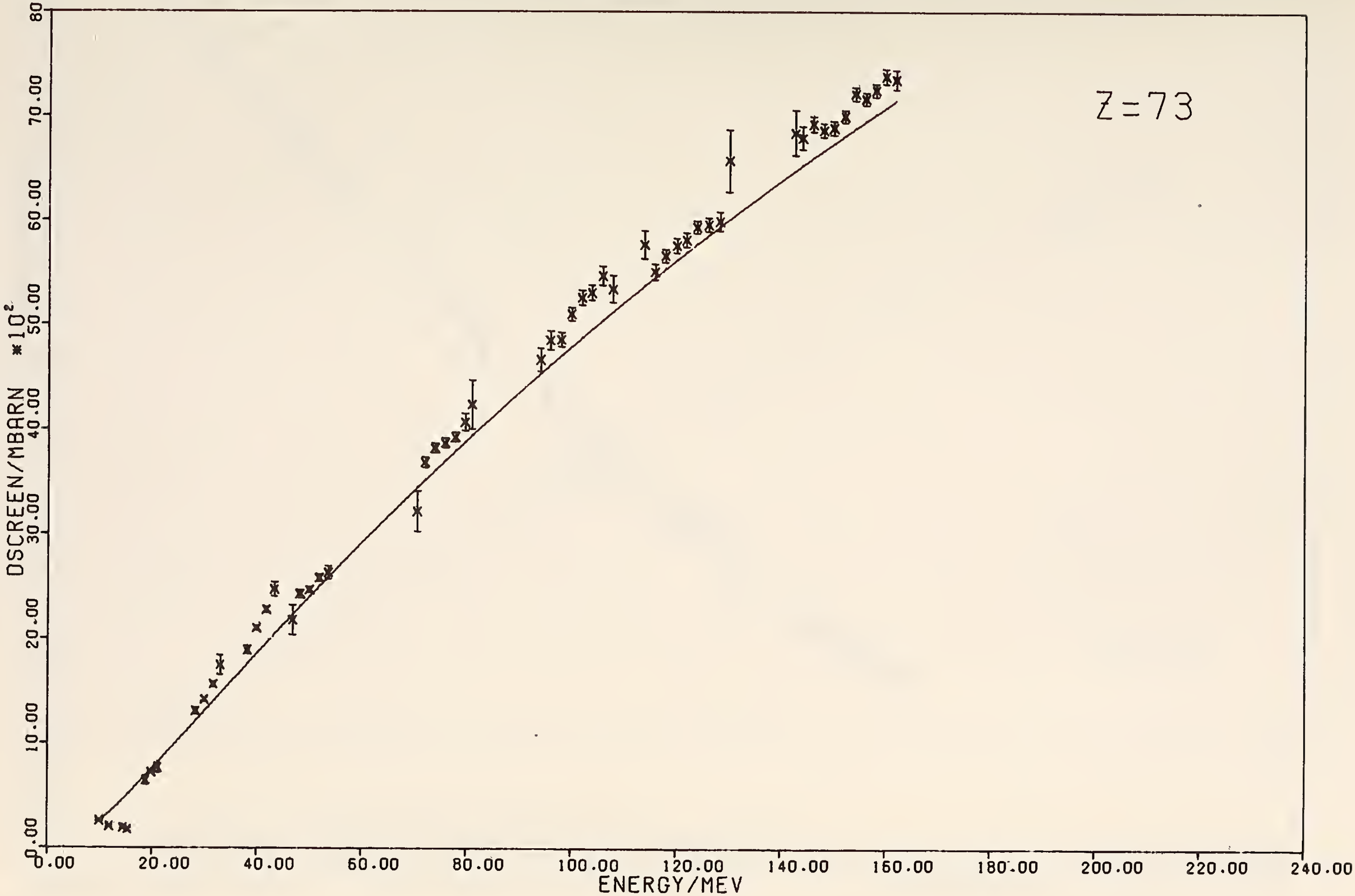


Figure 17 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for tantalum (derived from equation (42)). The curve gives the calculated screening correction obtained with relativistic form factors.

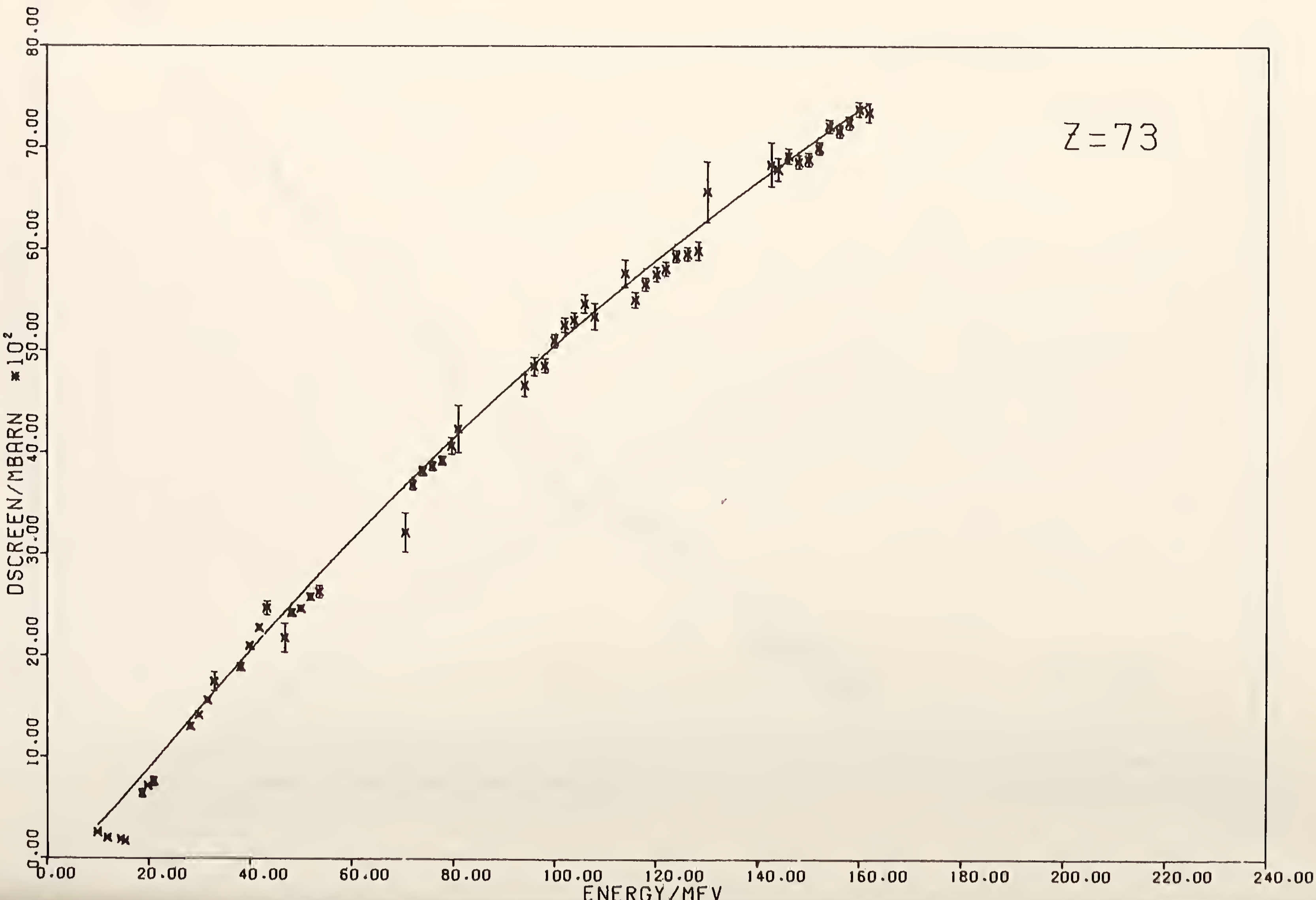


Figure 18 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for tin (derived from equation (42)). The curve gives the calculated screening correction obtained with nonrelativistic form factors in formula (20). The error bars display the statistical errors of the experimental data. The structure in the low energy part of the plot reflects the nuclear giant resonance.

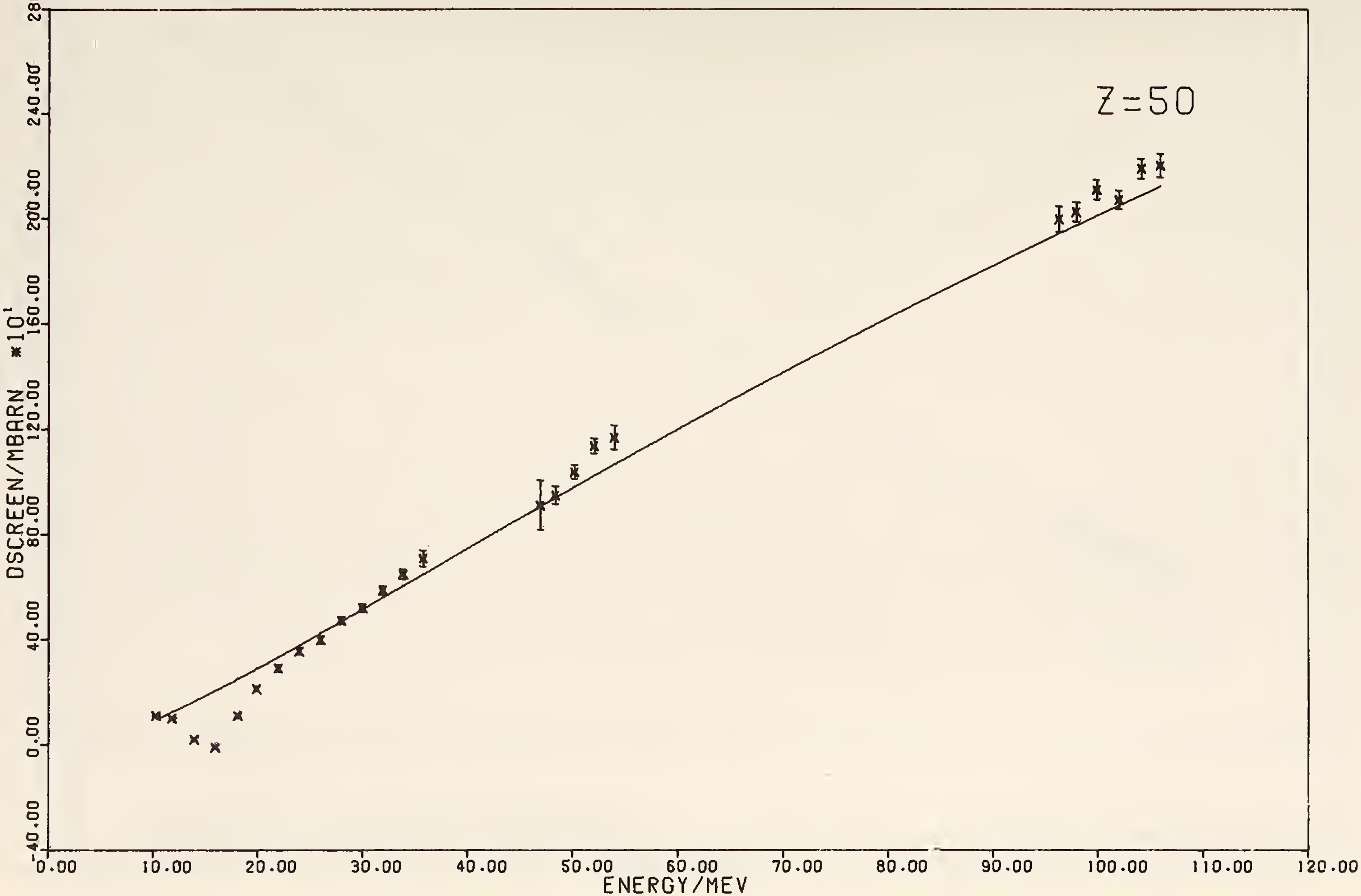


Figure 19 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for tin (derived from equation (42)). The curve gives the calculated screening correction obtained with relativistic form factors.

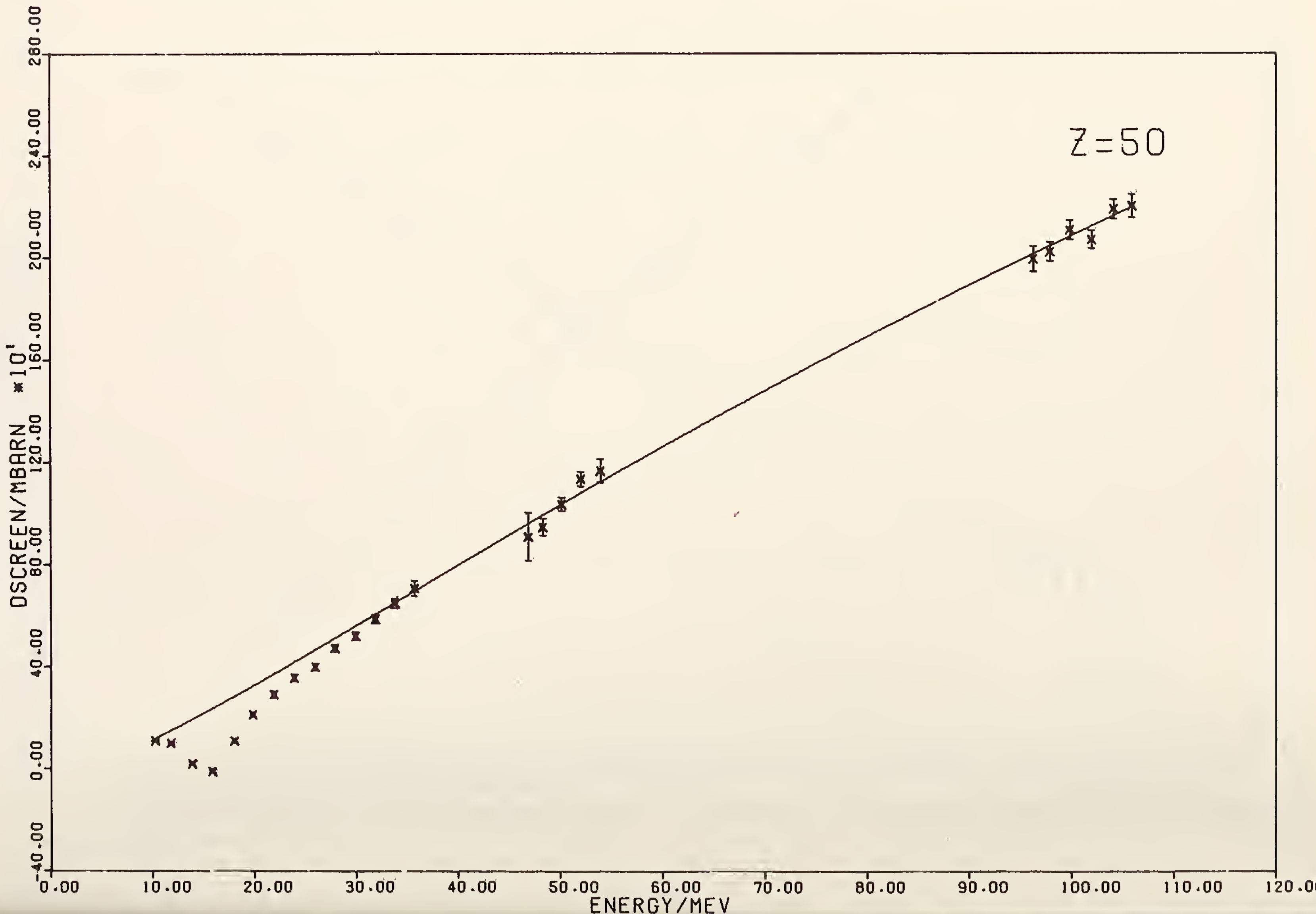


Figure 20 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for copper (derived from equation (42)). The curve gives the calculated screening correction obtained with nonrelativistic form factors in formula (20). The error bars display the statistical errors of the experimental data. The structure in the low energy part of the plot reflects the nuclear giant resonance.

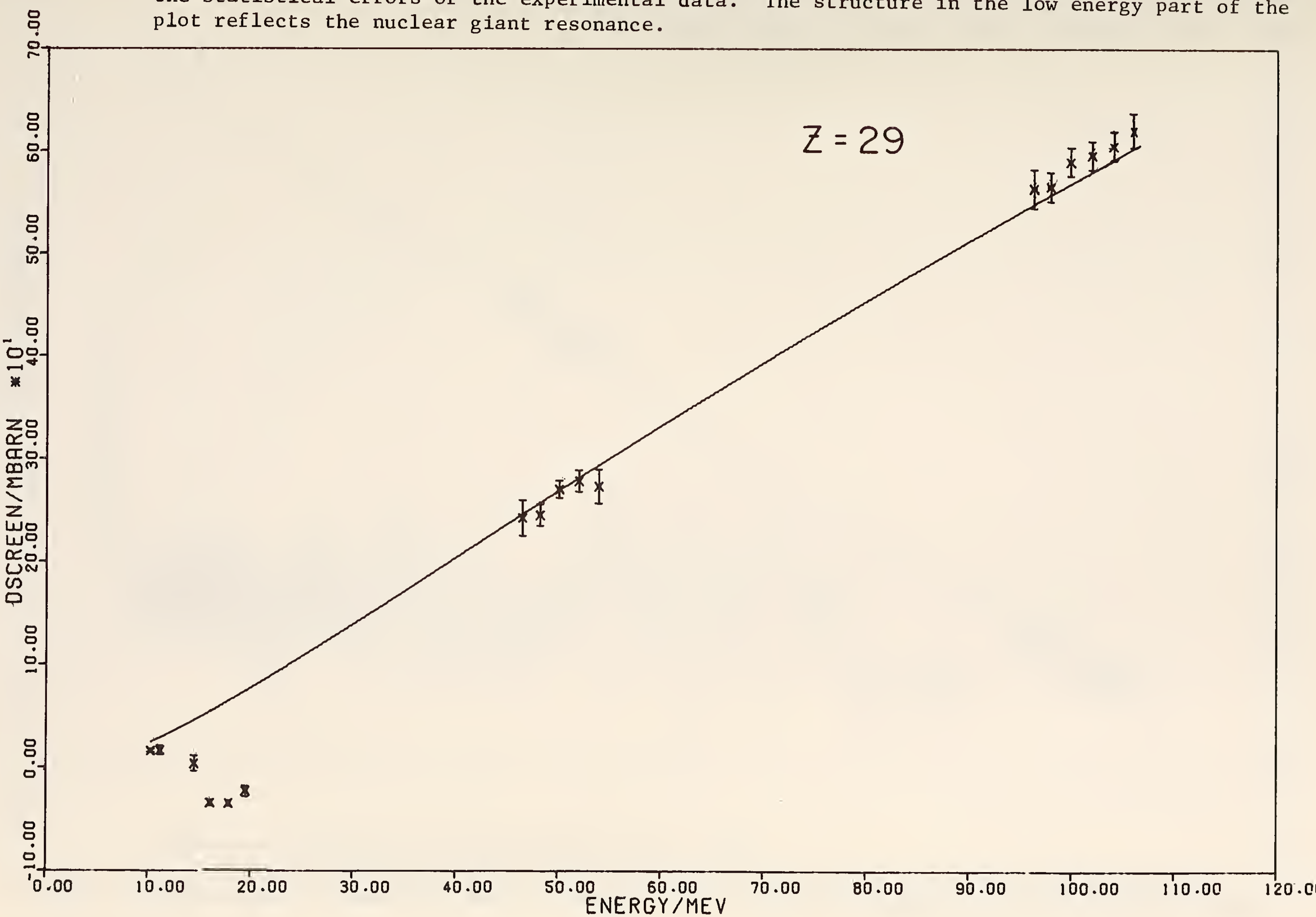


Figure 21 Experimental screening correction cross sections for pair production in the nuclear Coulomb field for copper (derived from equation (42)). The curve gives the calculated screening correction obtained with relativistic form factors.

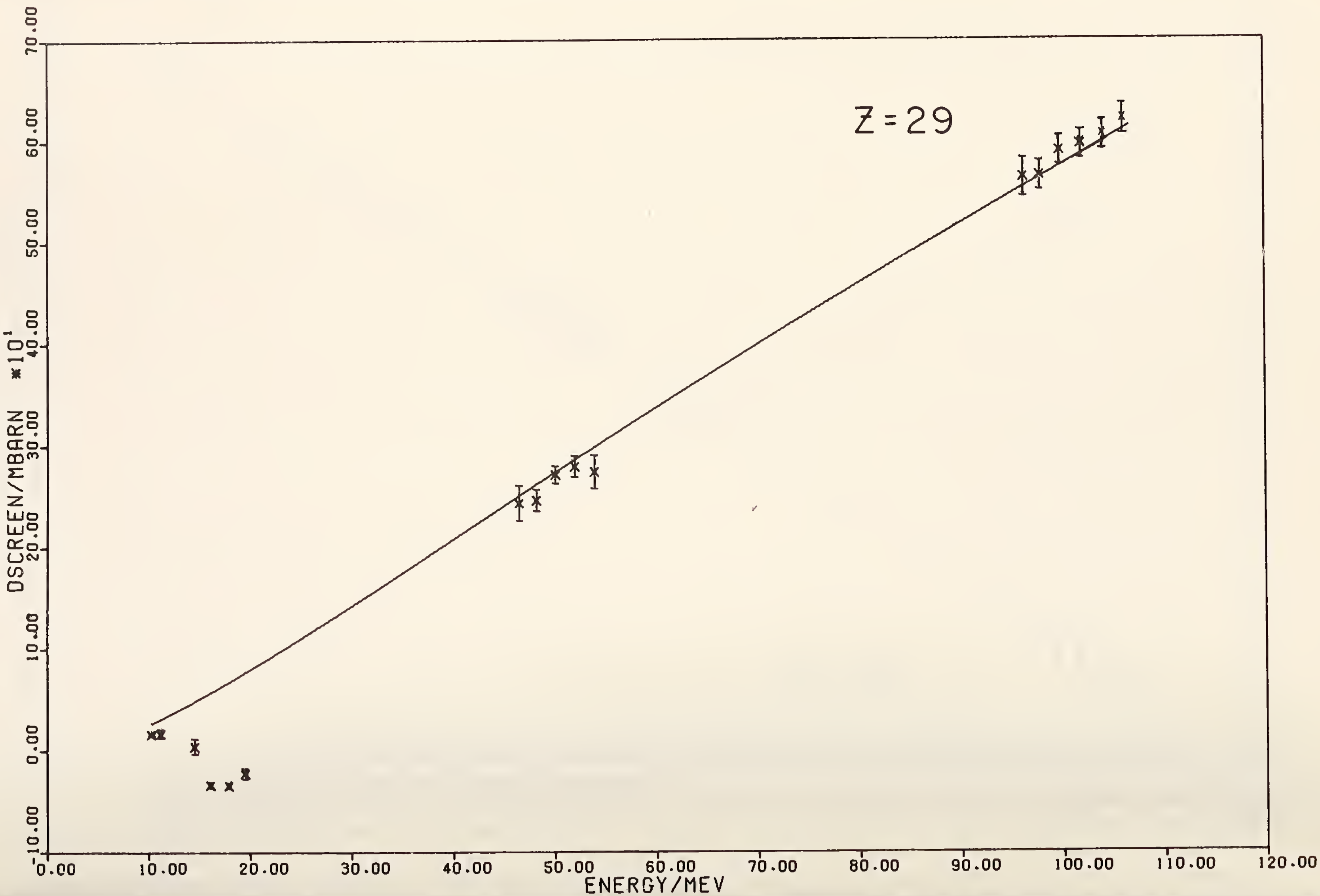


Figure 22 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$, for lead (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.

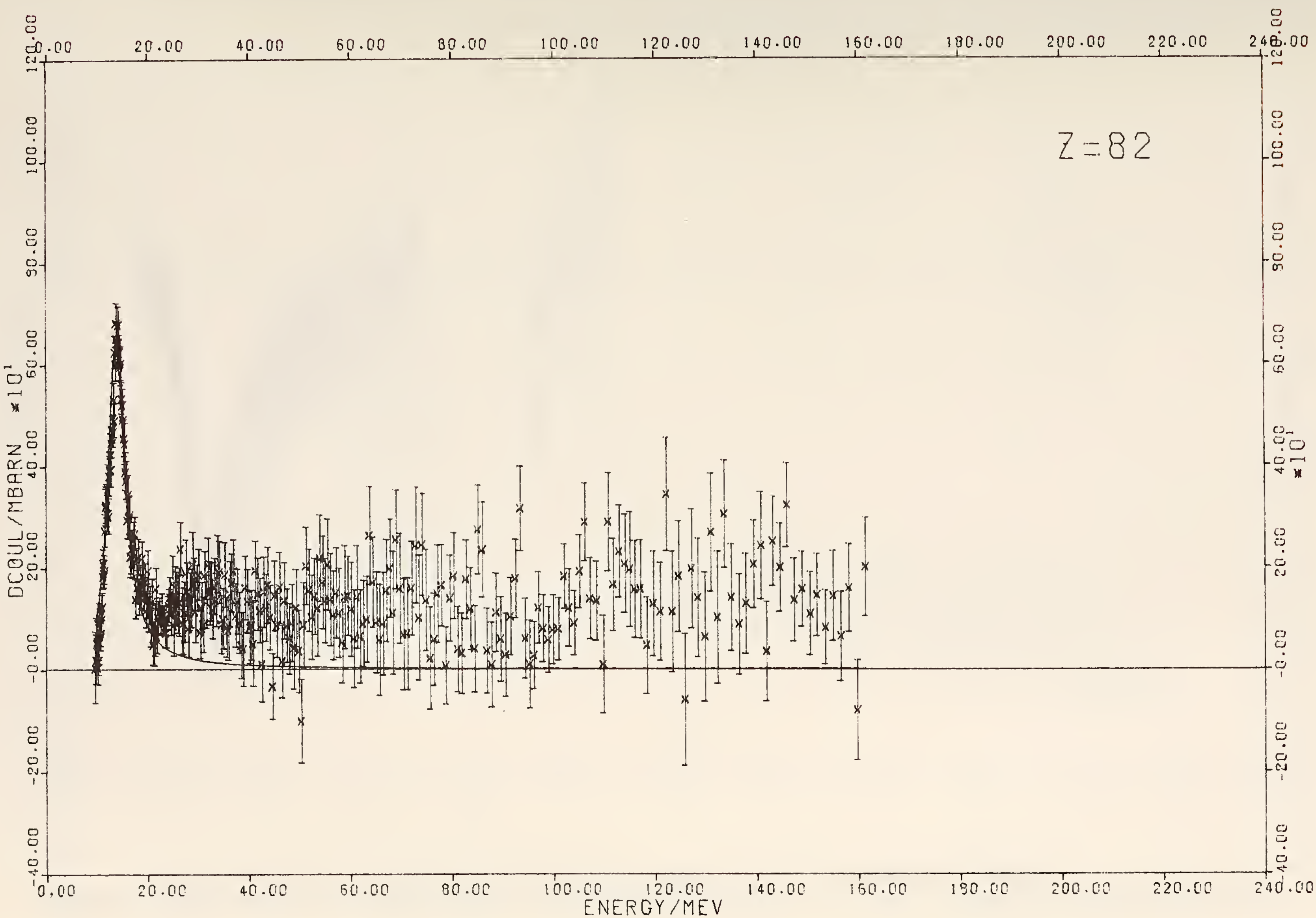


Figure 23 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$, for tin (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.

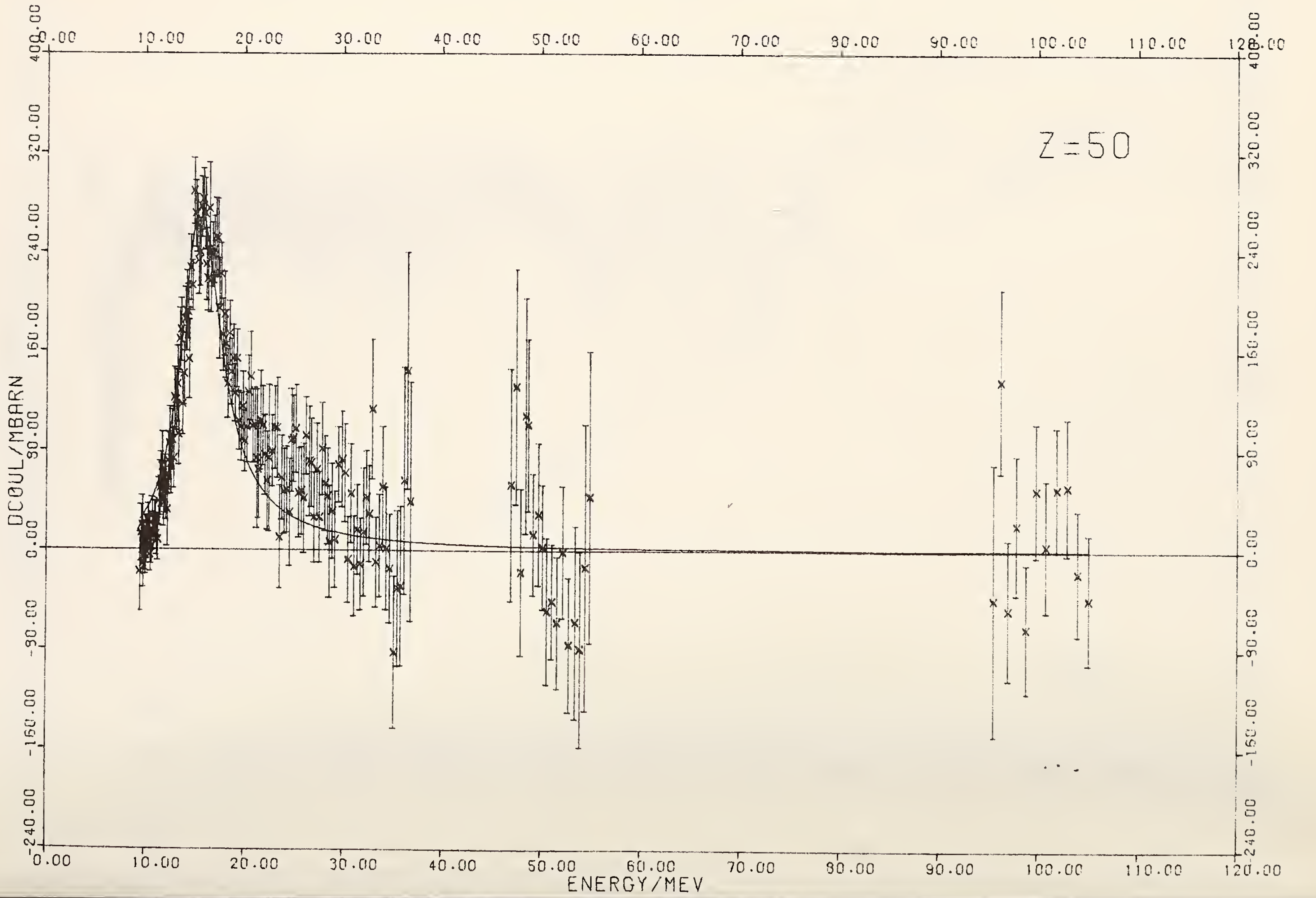


Figure 24 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for lead in the giant resonance region. The curve gives the (γ,n) cross section [29]. The error bars indicate one standard deviation of the statistical error.

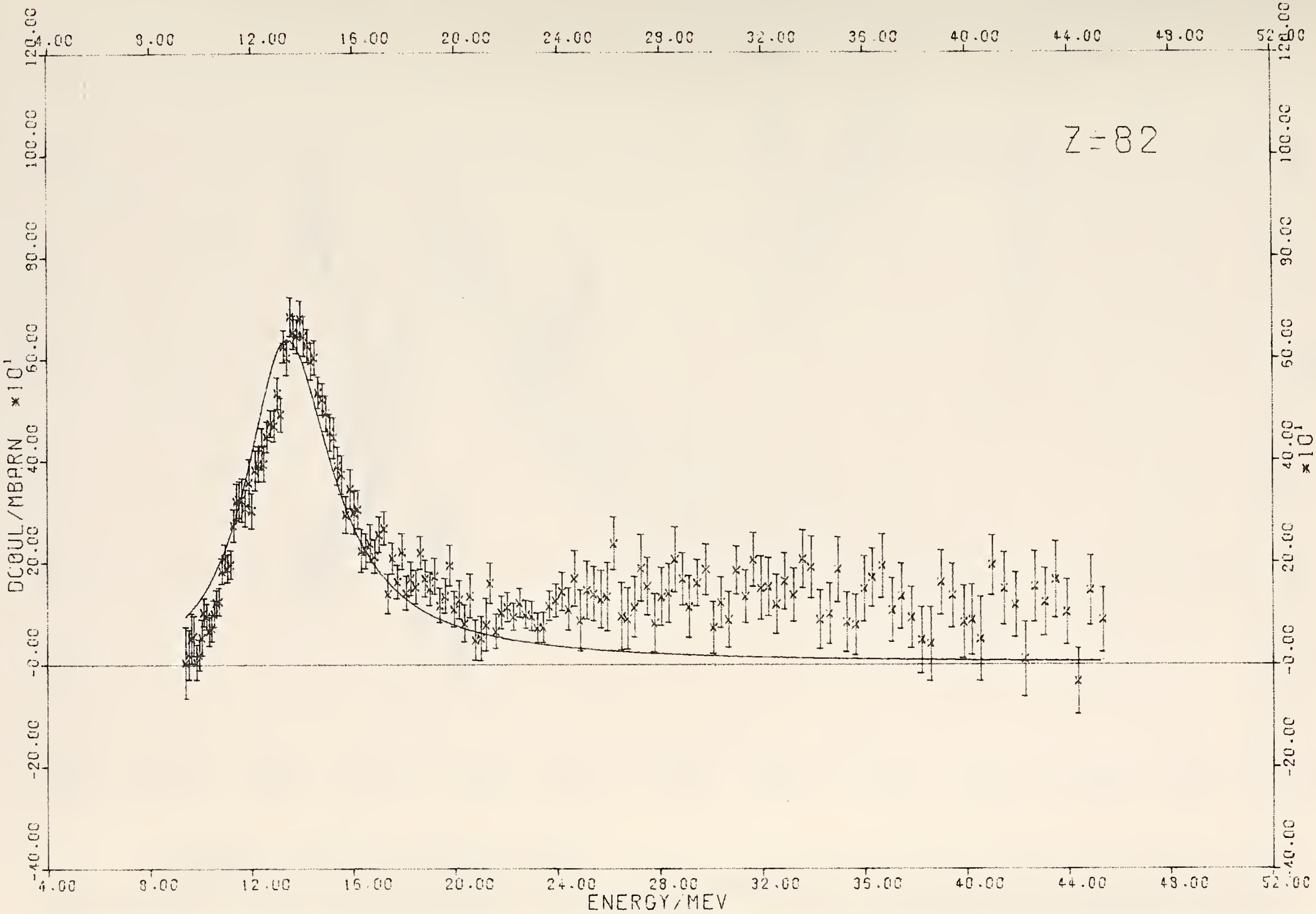


Figure 25 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for tantalum in the giant resonance region. The curve gives the (γ,n) cross section [29]. The error bars indicate one standard deviation of the statistical error.

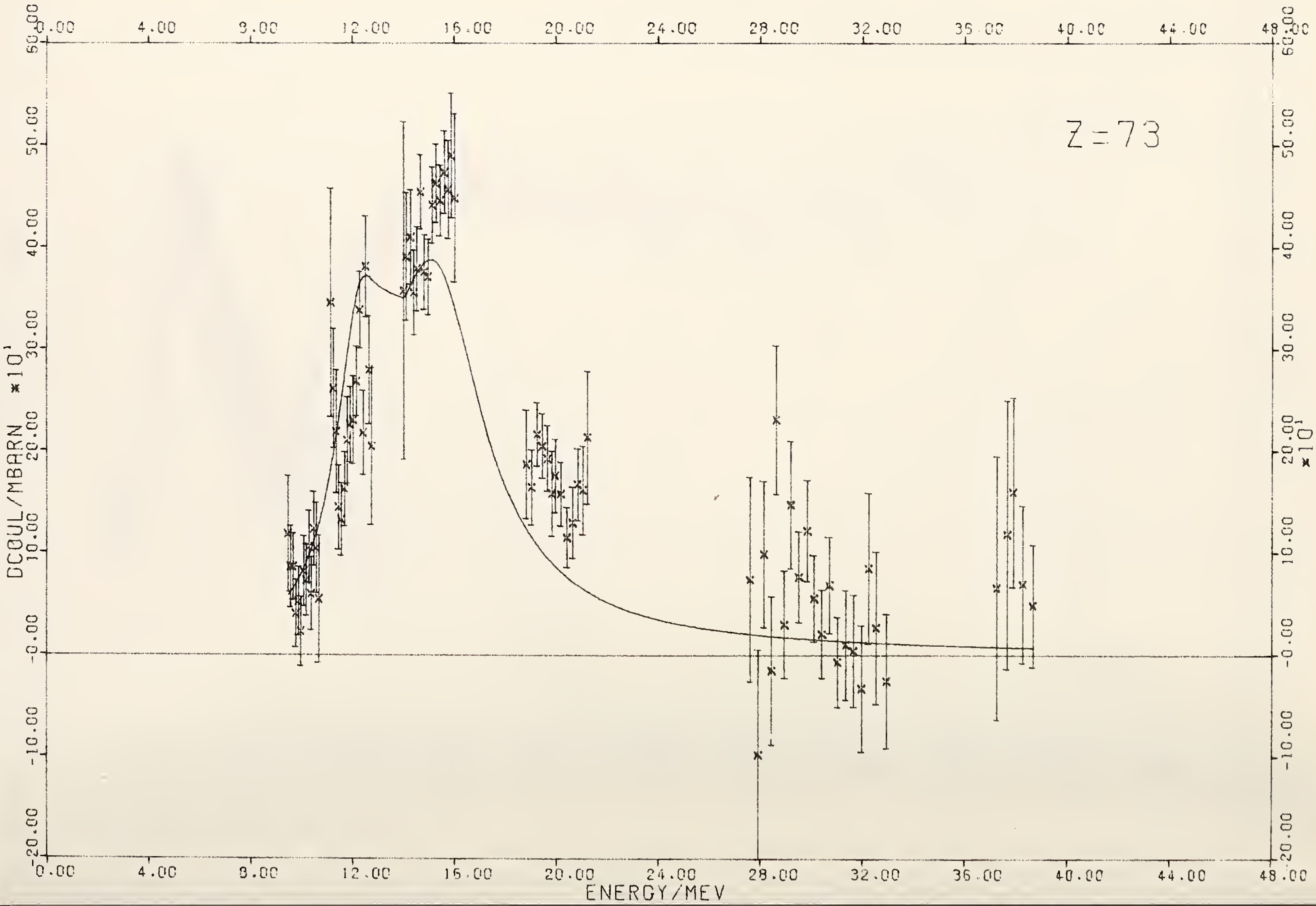


Figure 26 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for tin in the giant resonance region. The curve gives the (γ,n) cross section [29]. The error bars indicate one standard deviation of the statistical error.

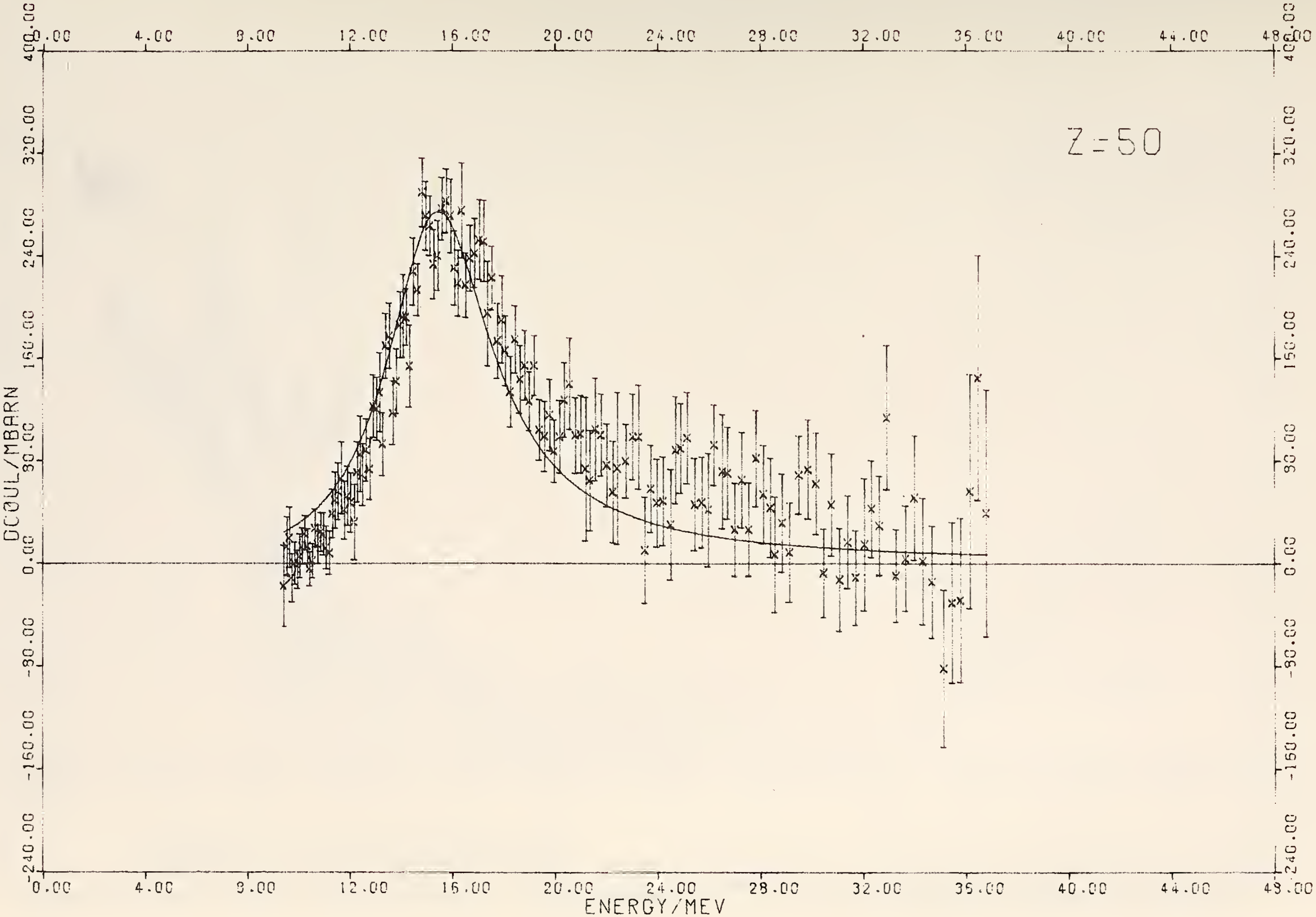


Figure 27 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for copper in the giant resonance region. The curve gives the (γ,n) cross section [29]. The error bars indicate one standard deviation of the statistical error.

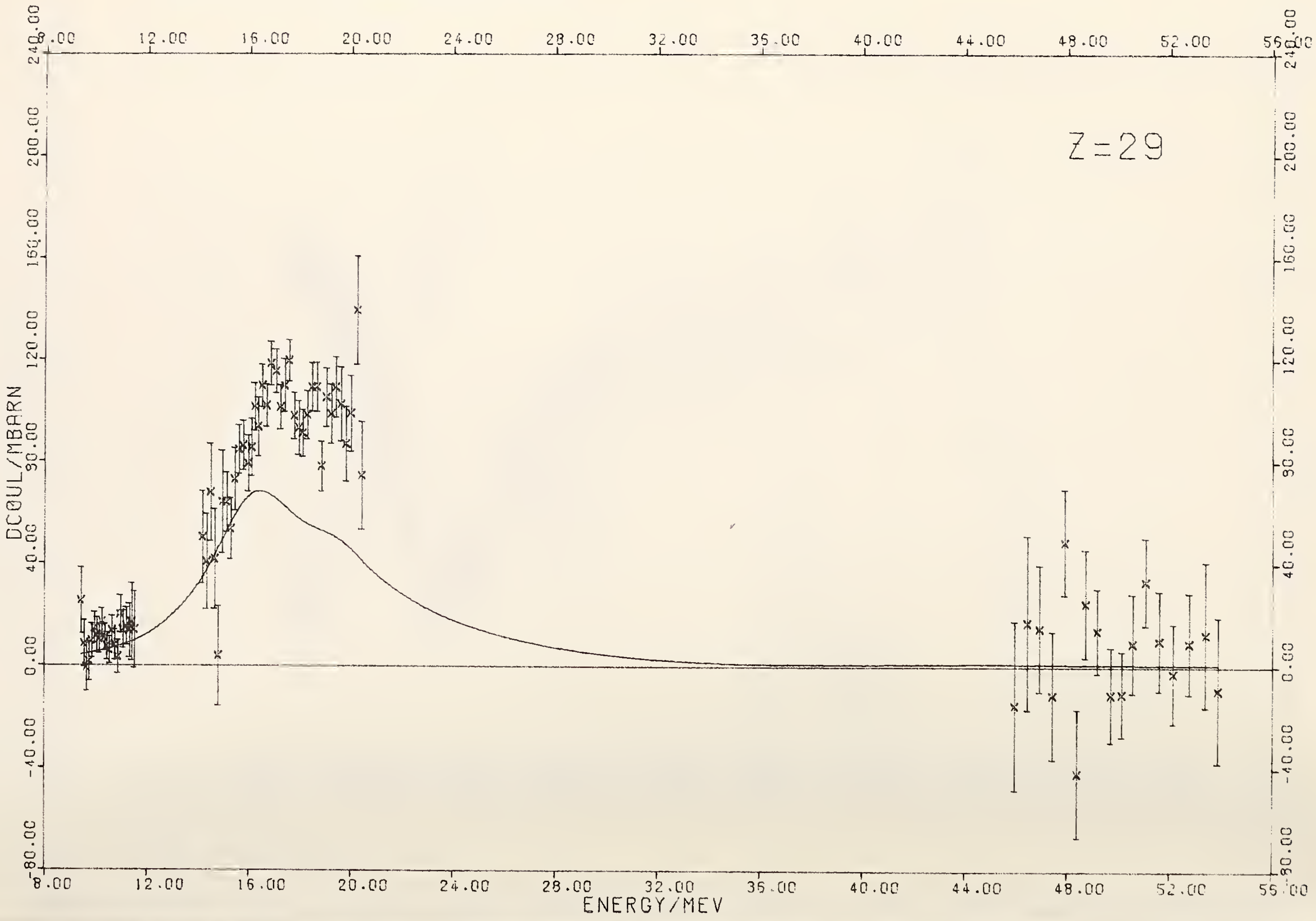


Figure 28 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for lithium (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.

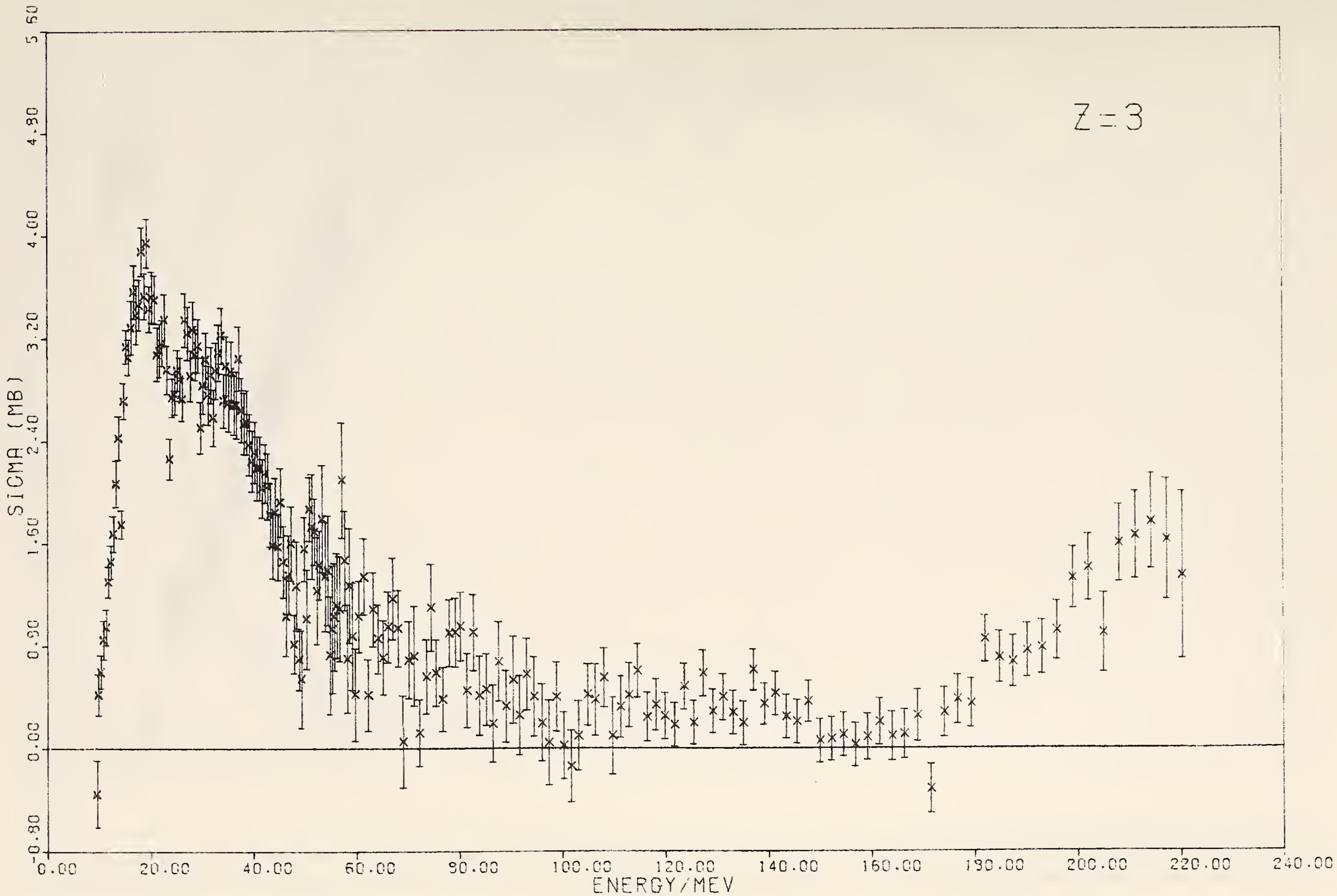
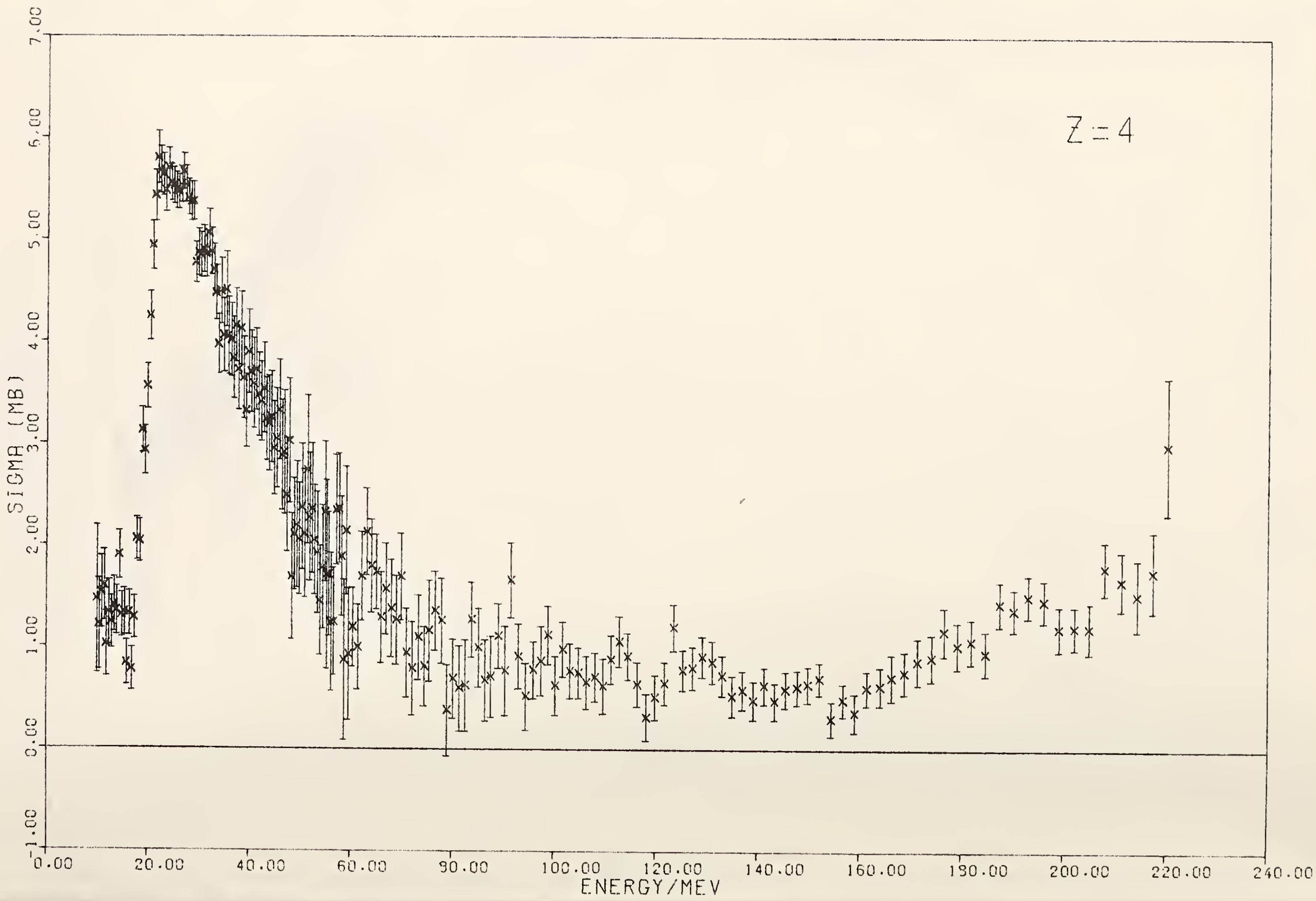


Figure 29 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for beryllium (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.



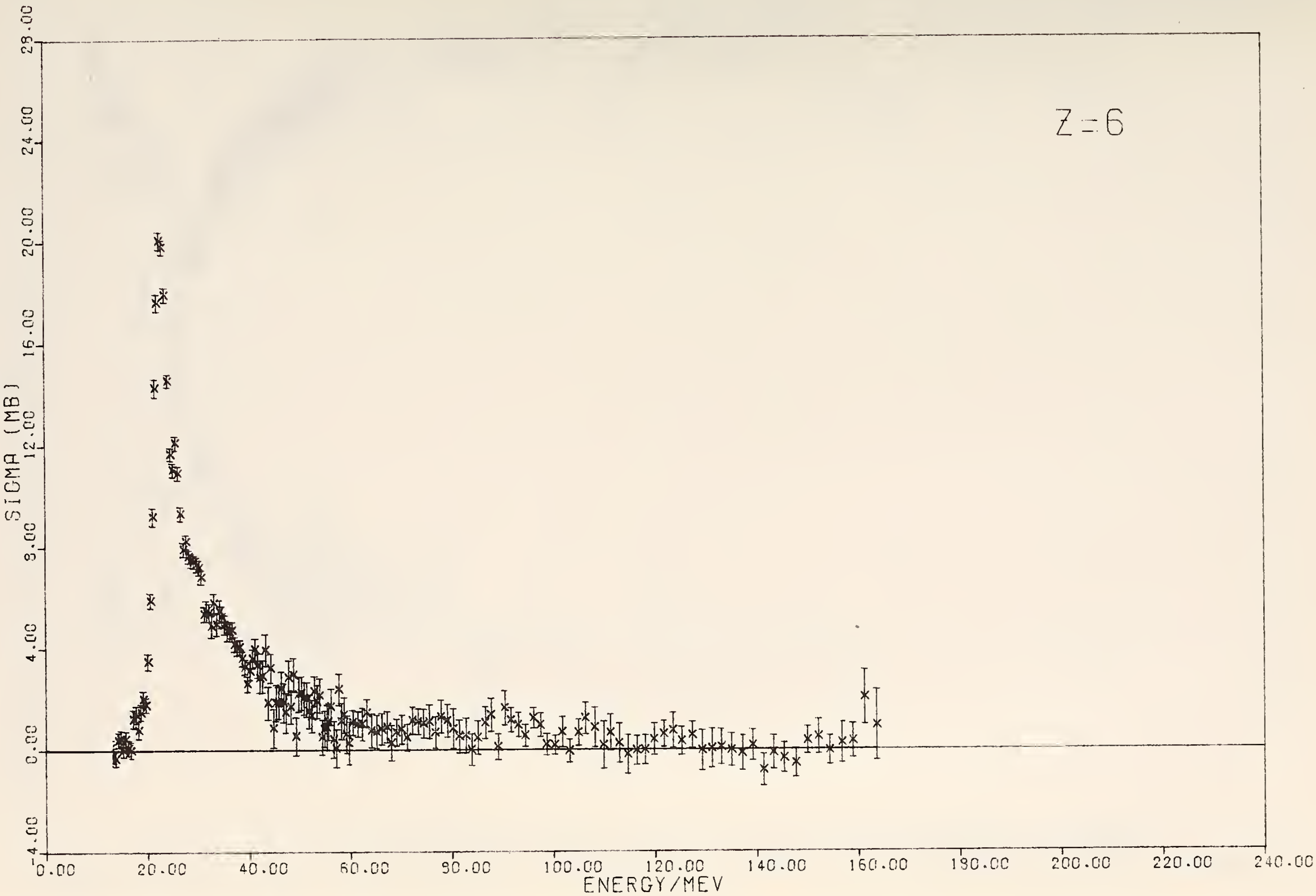


Figure 30 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for carbon (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.

Figure 31 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for oxygen (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.

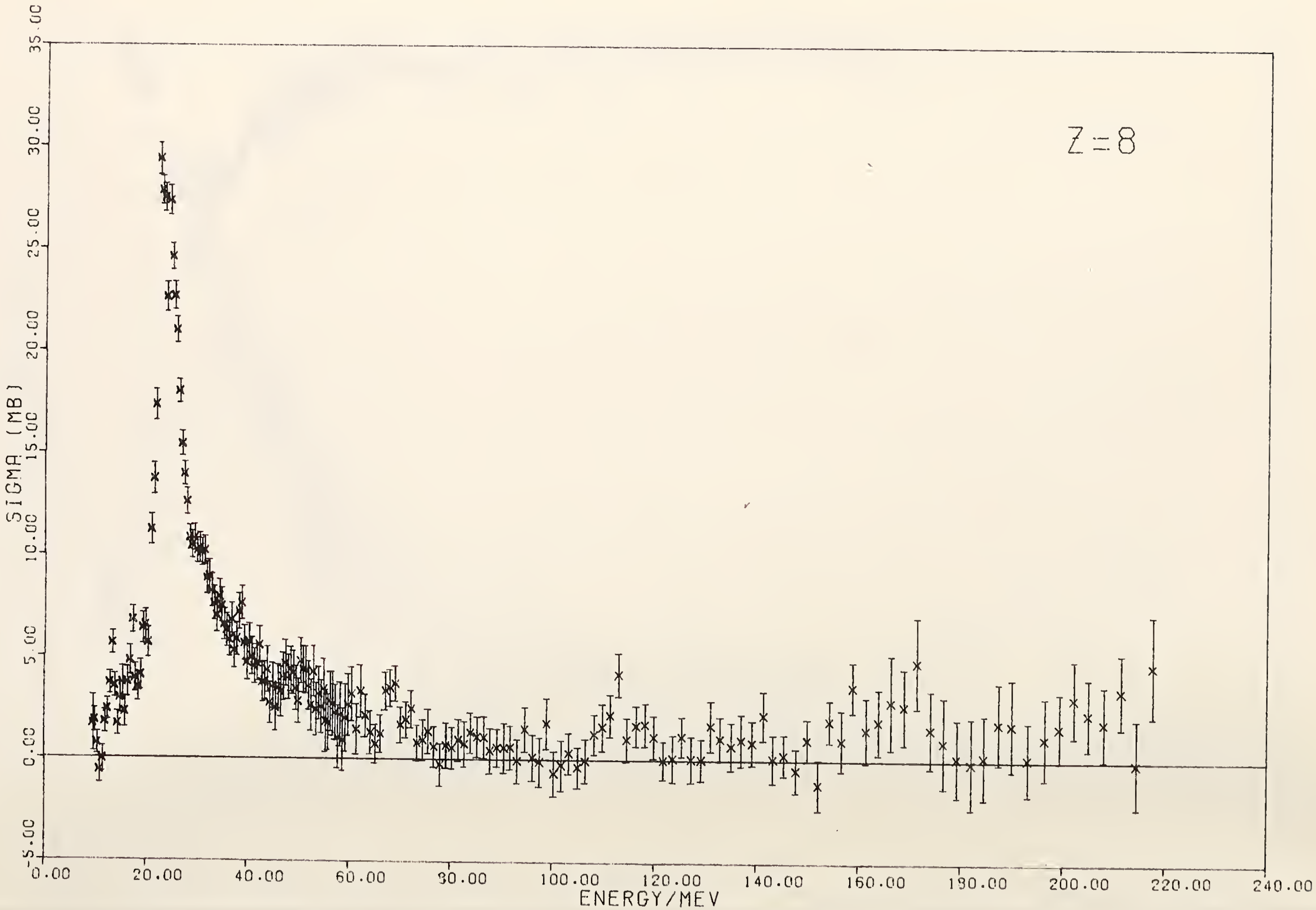


Figure 32 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for aluminum (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.

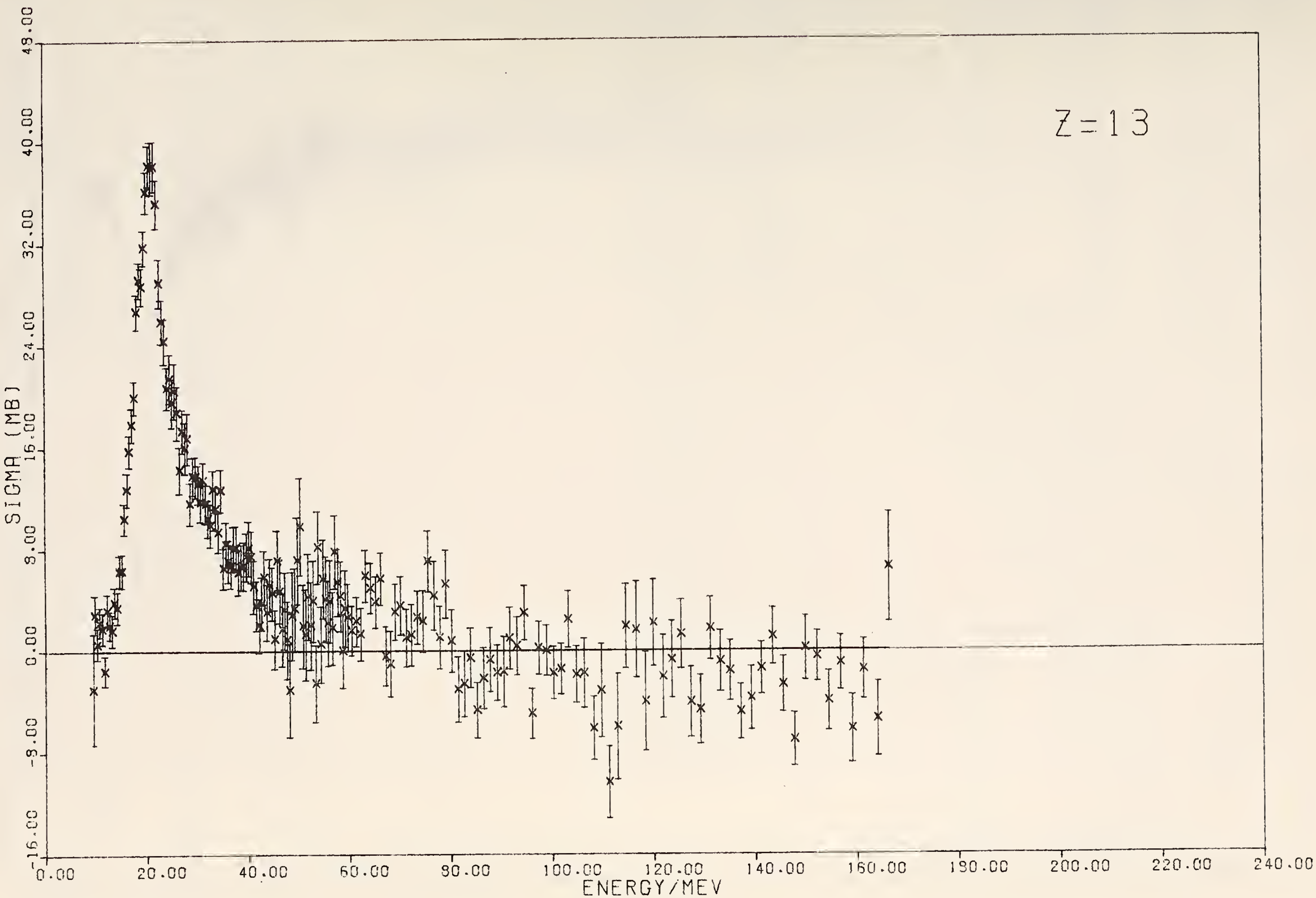
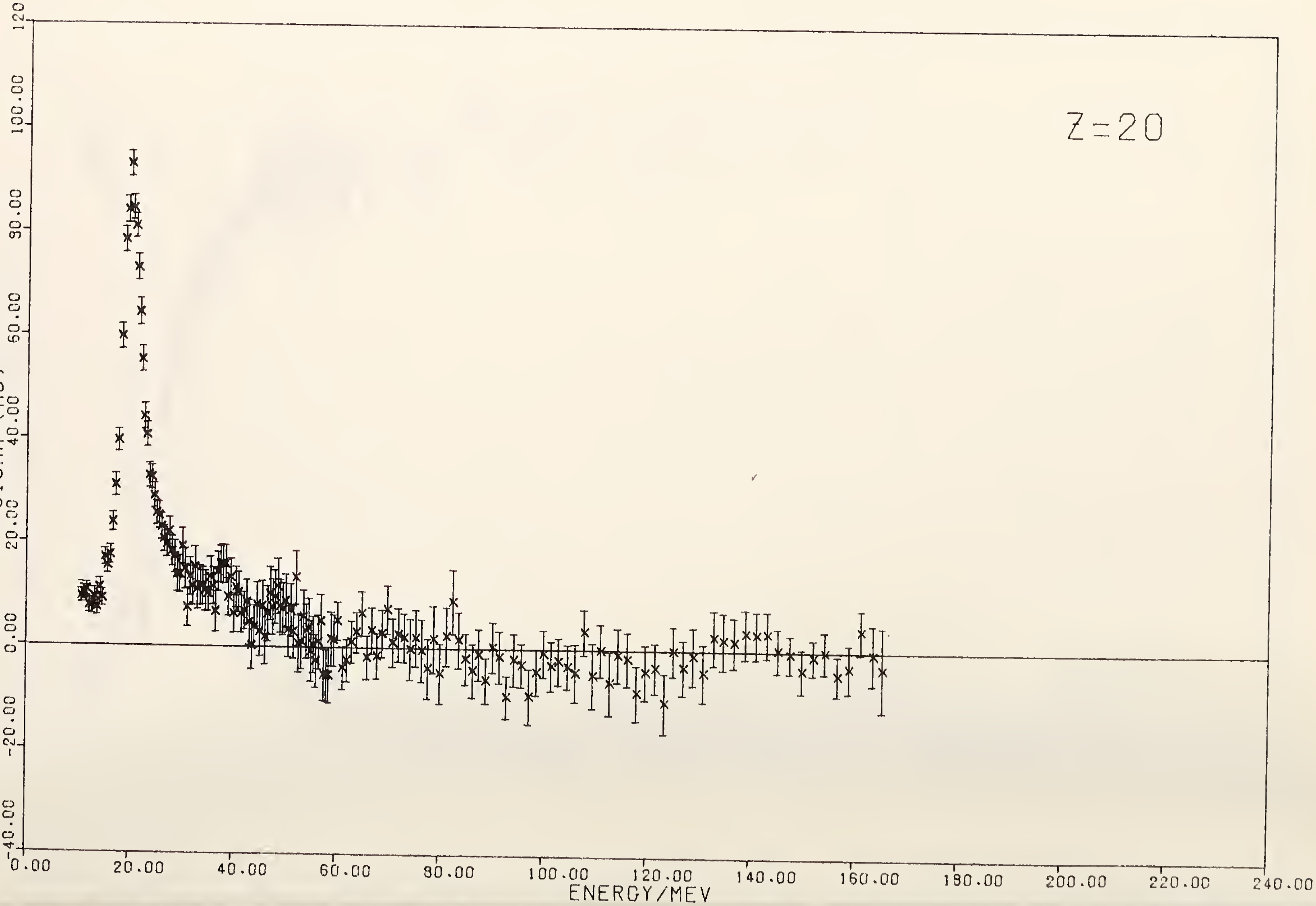


Figure 33 Total nuclear photoabsorption cross section, $\sigma_{nucl}(k)$ for calcium (obtained from equation (1)). The error flags indicate the statistical errors of the experimental points.



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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Atomic photoabsorption cross sections have been calculated in the energy range from 10 MeV to 350 MeV. For Pb, Ta, Sn and Cu total γ-ray absorption cross sections were measured between 10 MeV and 160 MeV and compared with the theoretical results. An estimate of the uncertainties in the calculated atomic cross sections is given.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Key words: Coulomb corrections; pair production cross section; screening corrections; total photon absorption cross section; total photonuclear absorption cross section; triplet production cross section.

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