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TOTAL CROSS SECTIONS OF C, Na, K, Ca FOR 14 MeV NEUTRONS

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TOTAL CROSS SECTIONS OF C, Na, K, Ca FOR

14 MeV NEUTRONS

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Contratto Euratom - CNEN per le Basse Energie

1. - INTRODUCTION.

Informations on the total neutron cross section are useful for studying nuclear models and reactions mechanisms. They are also very important from the reactor physics standpoind, particularly for certain substances (1).

Both these reasons have stimulated the authors to undertake a measurement of the total cross section of C, Na, K, Ca for the 14 MeV neutrons obtainable with the Cockroft-Walton generator of the Istituto di Fisica di Trieste.

The measurements has been performed using the transmission method and with an energy resolution of about 230 KeV.

2. - EXPERIMENTAL PROCEDURE.

2.1 Neutron source.

Neutrons were produced with the reaction $T(d,n)\ He^4$. The deuteron beam was accelerated to 400 KeV by the 600 KeV Cockroft-Walton generator of the Istituto di Fisica di Trieste, using a current of 50 μA. The tritium target was of the solid type consisting of a zirconium film about 7 mg/in.sq. thick, loaded with trintium gas.

In the experiment the neutrons emitted at an angle of 40° with respect to the beam direction were used. In order to determine the absolute value of the energy and the energy spread of these neutrons, due to the fact that the deuterons interact with the tritium nuclei with all the energies up to the maximum deuteron energy because they are slowed down by the zirconium while traversing the target, the following method has been adopted. Firstly, by doing α - n coincidence measurements, the angular distribution of the neutrons correlated with the alpha particles emitted at a fixed angle ϑ_α has been determined: to each angle ϑ_n it corresponds a deuteron energy E_d since the three quantities E_d, ϑ_n, ϑ_α satisfy a unique relation $f(E_d, E_n, E_\alpha) = 0$. Secondly, the energy distribution of the incident deuterons has been derived on the basis of the known cross section for the $T(d,n)He^4$ reaction. Thirdly, assuming this cross section be indipendent of ϑ_n, the energy distribution of the neutrons emitted in the direction used for the experiment (ϑ_n fixed) has been calculated, making use of both the deuteron energy distribution and the reaction cross section.

The energy distribution of the neutrons used in the transmission experiments and derived by the method explained above is reported in Figure 1. The horizontal bars represent errors due to the size of the neutron detector. To characterise energetically the incident neutron beam, the width at half-height of the distribution has been considered. Thus, the measured cross-sections have been quoted at an average neutron energy of 14.68±0.23 MeV. The average value is known with an incertainty due to the finite size of the detector.

2.2 Neutron detection.

The transmission measurements have been performed by means of a stilbene crystal spectrometer. Figure 2 shows a block diagram of the apparatus. The discrimination between neutrons and gammas has been achieved with the well known space charge method (2).

The stilbene crystal (1" diameter ×0.1" height) was mounted on a RCA 6810-A photomultiplier. The optimum potential difference between the last dinode and the anode for the space charge operation was 5.6 volts and was mantained quite constant using mercury batteries. This precaution has been required by the fact that variations of the order of a few percent in the potential difference caused variations of the order of as much as 10 percent in the height of the pulses due to protons. On the other hand such variations were to be expected using

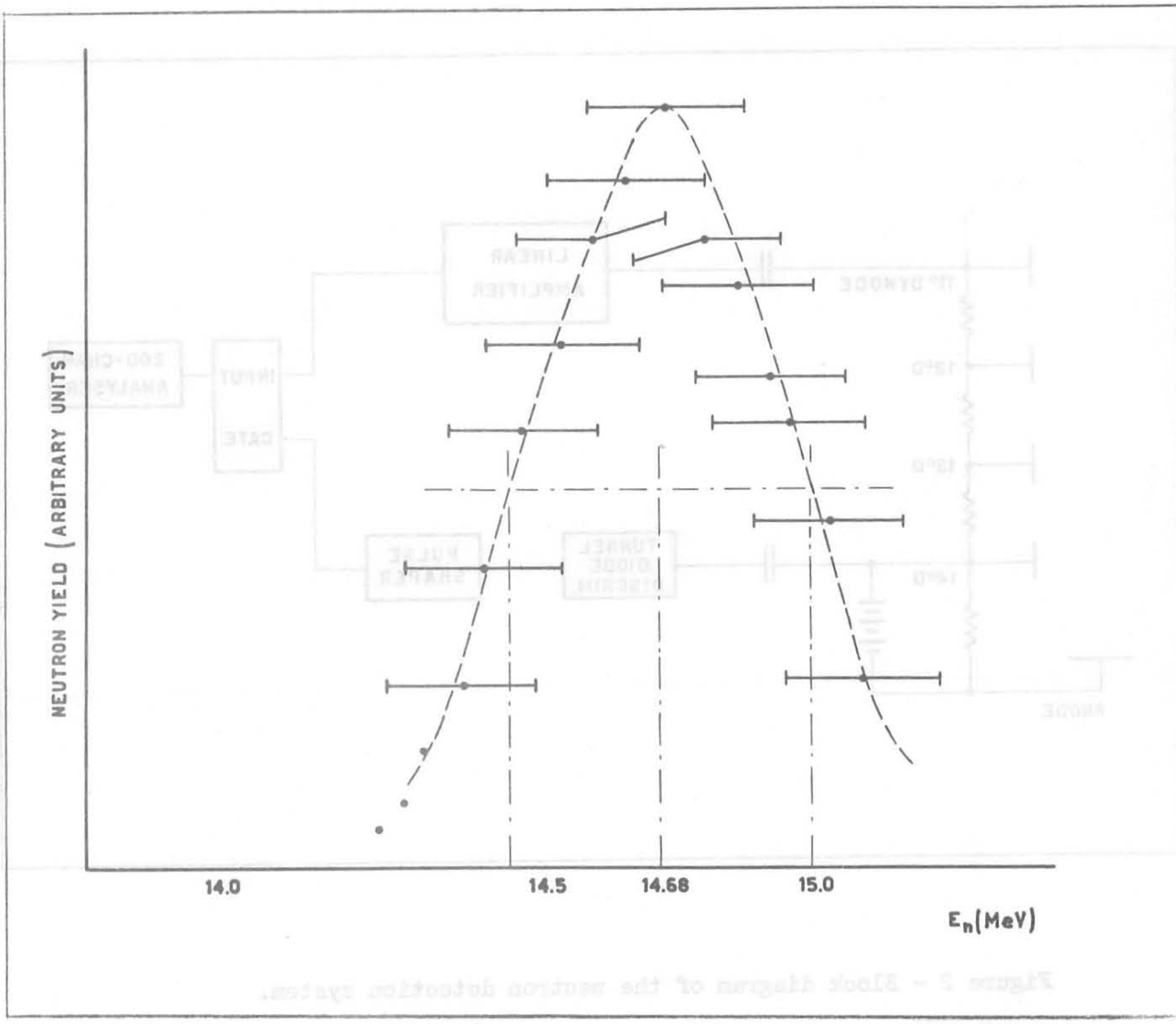

Figure 1 - Energy distribution of the neutron beam used for the transmission measurements.

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electronic power supplies since a single transmission measurement lasted several hours.

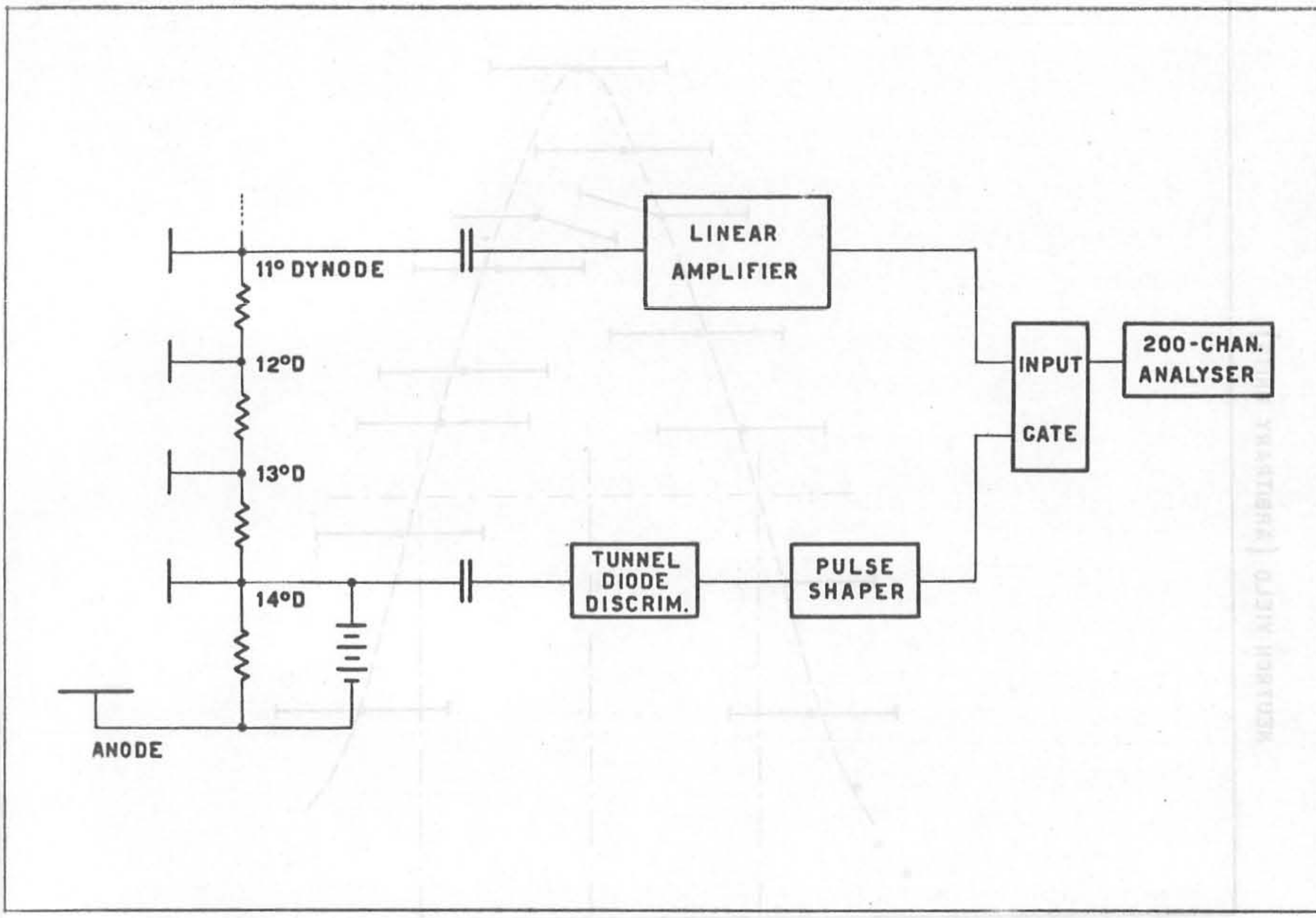

Figure 2 - Block diagram of the neutron detection system.

The positive pulses due to protons taken from the 14th dinode and discriminated with a diode "tunnel" were used to open a gate. The pulses taken from the 11th dinode, proportional to the energy dissipated in the crystal by either the recoil protons or the electrons, were fed via an aplifier to the imput of the gate. Only the recoil proton pulses were then registered by the 200 channels pulse height analyzer. The bias setting of the gate was chosen in order to eliminate the low proton pulses, due to neutrons produced by (d,d) reactions, and to reduce also the background and the pulses coming from neutrons inelastically scattered by the samples. The observation of the detected proton recoil spectrum allowed to choose the discrimination level of the diode tunnel so that to obtaine the greatest counting stability and to control any possible shift of the spectrum.

The transmission measurements were monitored by counting the alpha particles from the reaction.

The alpha particles detector consisted of a Si solid state detector of 1 cm^2 surface. To discriminate against the deuterons a thin aluminium sheet was placed in front of the detector. As a consequence, the alpha energy spectrum resulted slightly shifted in energy but its shape was not distorted. This spectrum was observed with a pulse height analyzer and then the bias setting of a window discriminator was chosen to let the alpha particles under the peak of the spectrum be counted.

2.3 Samples.

The samples used for the transmission measurements were natural elements and all of cylindrical shape. Some of their characteristics are collected in Table 1.

Sample	Diameter (MM)	Lenght (MM)	Weight (g)	Purity (%)
C	23.7	77.9	59.376	Nuclear graphite
Na	56.7	184.0	457.36	99.9
K	25.0	144.6	62.87	99.5
Ca	23.4	127.0	85.15	99.5

Table 1 - Data on the samples.

During the measurements the center of the samples was at a distance of 20 cm from the source and 40 cm from the detector.

3. - MEASUREMENTS AND RESULTS.

For each sample the total count under the recoil proton pulse spectrum registered by the 200 channel analyzer was taken with the sample in the neutron beam, C, with the sample out, C_o, and with a brass rod interposed between the neutron source and the detector, C_b; the last count gave the laboratory back-ground. Then, the total cross section was obtained from the relation

$$\sigma_T = \frac{1}{N\ell} \ln \frac{1}{T} \qquad (1)$$

where N is the number of nuclei per cm^3 in the sample, ℓ is the thickness of the sample and

$$T = \frac{C - C_b}{C_o - C_b} \qquad (2)$$

is the transmission of the sample.

The run of measurements was repeated several times in order to ascertaine there were no drifts in the behaviour of the experimental equipment.

The results are collected in Table 2.

Sample	σ_T (barns) experimental	$\Delta\sigma_T$ (%)	σ_T (barns) calculated
C	1.39 ± 0.02	1.2	1.149
Na	1.74 ± 0.03	1.6	1.587
K	2.14 ± 0.04	2.1	2.088
Ca	2.17 ± 0.03	1.5	2.116

Table 2 - Values of the total neutron cross-sections.

4. - ERRORS AND CORRECTIONS.

The cross section values reported in Table 2 were corrected for background and single in-scattering effect.

The background correction was always less than 2%.

The correction for in-scattering effect was computed using the formula given by Manero [3] valid for the case where the target to sample distance is not equal to the sample to detector distance. The errors calculated with that formula amounted to 1.1% for C, 10.5% for Na, 2.7% for K and 2.4% for Ca.

A correction for double in-scattering was also estimated using the formula given by Conner [4]. This was appreciable only in the case of Na sample and amounted to a maximum of about 1%. With this correction the total cross section for Na would raise to about 1.76 barns.

The measured values of cross sections are presumably affected by an error coming out from the fact that neutrons inelastically scattered from the samples into the detector can give a proton recoil pulse which is registered. In order to evaluate this contribution one should know the differential cross section for the first excited levels of the studied nuclei.

However very scarce information is available in this respect; an estimation can be made only in the case of Na^{23} where the cross section for neutron scattering from the first excited level turns out to be smaller by more than one order of magnitude in the forward direction than the cross-section for elastic scattering (5). Therefore we assume that the inelastic in-scattering correction is much less important than the elastic one, which is of the order of only 1 or 2%.

The same conclusion can be drawn also for the contribution from the (n,2n) reaction, being the cross section for these reaction 2 or 3 order of magnitude smaller than the total cross section.

The errors $\Delta\sigma_T$ listed in Table 2 were computed taking into account the statistical errors of the counting measurements and the errors in the in-scattering corrections.

5. - CONCLUDING REMARKS.

The results of our measurements are plotted in Figure 3, together with those obtained by several authors for neutron energies of the order of 14 MeV. As a general behaviour the agreement is quite good; one may however observe that for the two lighter elements the values of σ_T are slighty higher than the average one's, the reverse happening for the two heavier elements.

It is well known that the problem of the determination of the total cross section for the neutron-nucleus interaction has been faced with good results by the optical model theory in its simpler (10) or more advanced form (11). In the simpler form the variation of σ_T with energy or with nuclear radius R, can be accounted for by the relation:

$$(3) \qquad \sigma_T = 2\pi \, (R+\bar{\lambda})^2$$

where $\bar{\lambda}$ is the neutron wave length divided by 2π. On the average this prediction is quite satisfactory, although it does not account for the oscillations superimposed on the average trend and whose amplitudes amount to as much as 25% of the average values at low energies and are tipically 10% at the higher energies. These giant resonances were first observed by Barshall (12) and are interesting not only the energy variations of σ_T but also the variations against the mass number A. In the context of the optical model the oscillations are seen to result from the interference between the part of the neutron wave which has traversed the nucleus with that part that has gone around. Peterson (11) gives a condition for the raising of maximum or minimum values in the oscillations; he prescribes that the average phase difference, Δ, between the wave traversing the nucleus and that going around must be:

$$(4) \qquad \Delta = \frac{4}{3} \, \alpha \, (K_{in}-K_{out}) = n\pi$$

where $n = 1, 3, 5, \ldots$ for a maximum in σ_T

and $n = 2, 4, \ldots$ for a minimum in σ_T

In the expression (4) K_{in} and K_{out} are the wave numbers inside and outside of the nuclear well potential and α is a number somewhat bigger

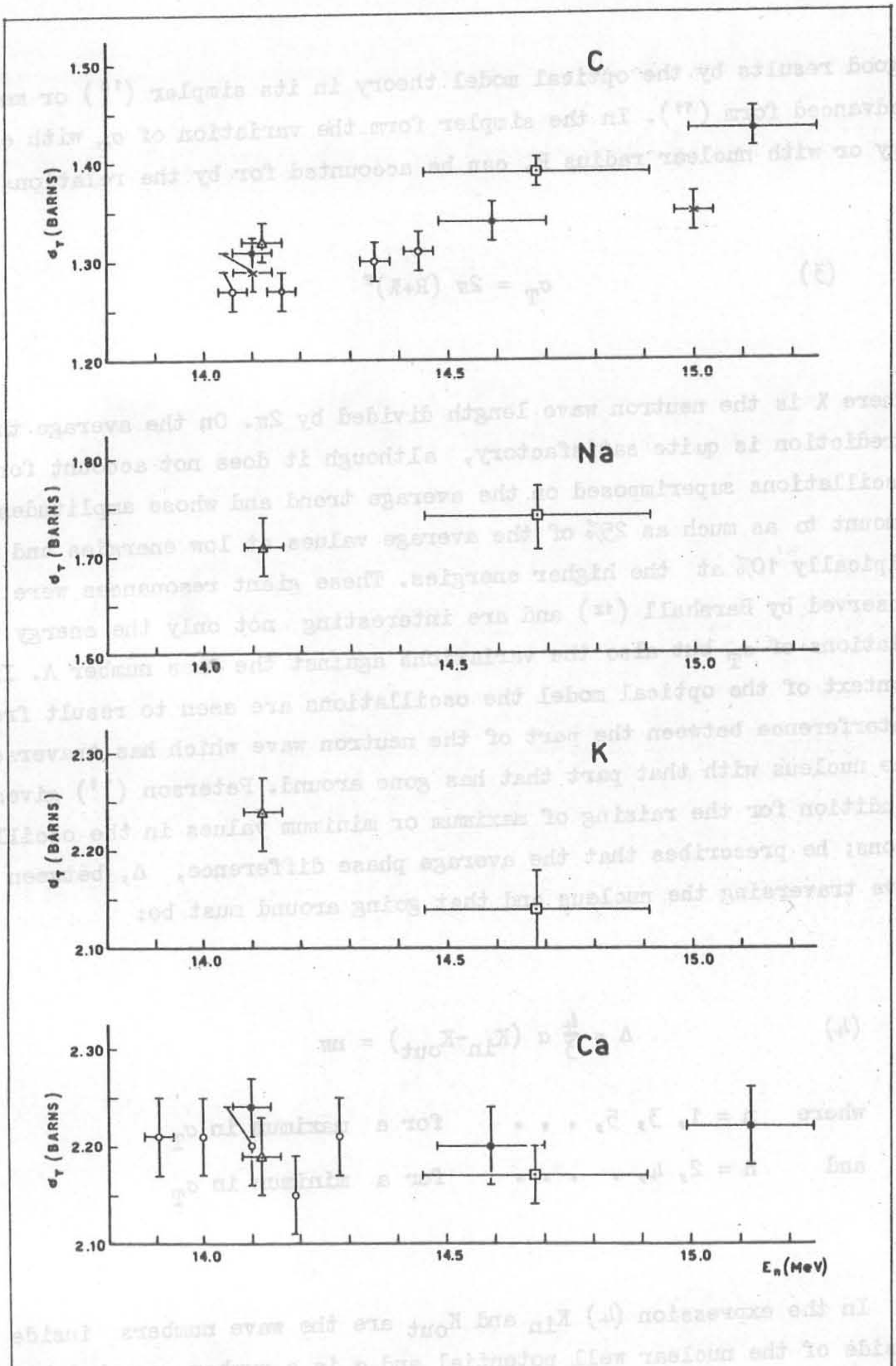

Figure 3 - Data on total cross-sections. Δ: Ref.(6),
•: Ref.(7), o: Ref.(8), x: Ref.(9),
□: Data of present work.

than 1, allowing for the increased path length inside the nucleus due to refraction effects.

The mass numbers of the elements examined in our investigation are contained between the first maximum and the first minimum of the total cross-sections, so that we may expect a slighty decrease of the measured σ_T in comparison of the calculated one's from (3).

In Figure 4 are reported the measured values of σ_T for C, Na, K and Ca, and the behaviour of σ_T as calculated from the formula (3) of Feshbach and Weisskopf [10], using $1.4\times A^{1/3}$ for the nuclear radius.

The agreement is contained within the limits previously extabilished; one may however observe a general trend in the reduction of the increasing values of σ_T against $A^{1/3}$ as is just foreseen by the behaviour of the giant resonances. The rate $\sigma_T/2\pi\,(R+\lambda\!\!\!^{-})^2$ is reported in Figure 4 with the dotted line and it reveals the existence of the mentioned behaviour.

Obviouly a more remarkable result could be obtained using more data on total cross sections corresponding to increasing values of A.

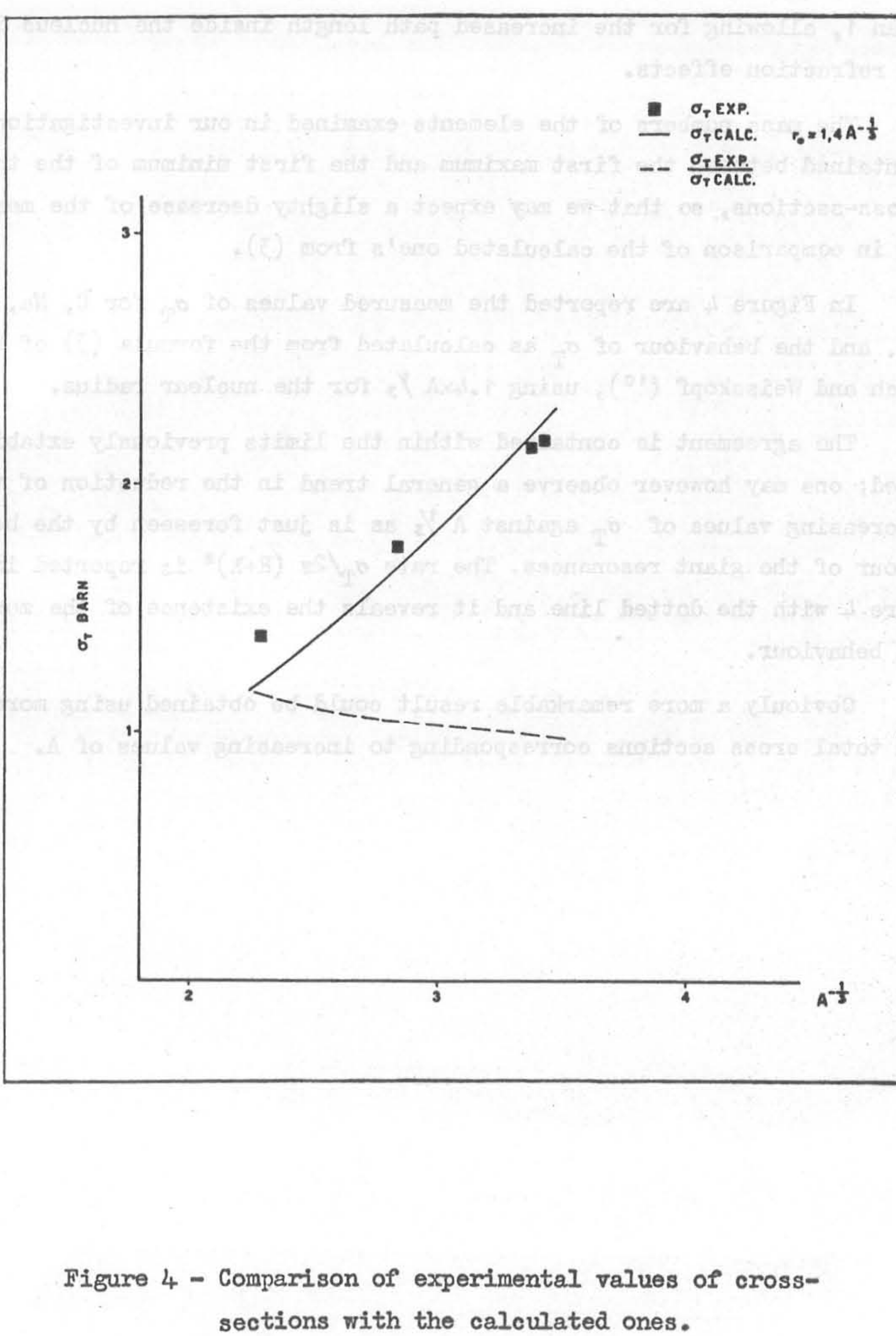

Figure 4 - Comparison of experimental values of cross-sections with the calculated ones.

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