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**ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ**

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**ЕФИ-456(63)-80**

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**EXCITATION FUNCTION OF PHOTOPRODUCTION OF  
CUMULATIVE PROTONS ON NUCLEI**

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New experimental data on the energy dependence of pre-exponential constant  $C_p$  in the representation  $\rho = f/\sigma_t = C_p \cdot \exp(T/T_0)$  of the invariant normalized cross section of cumulative proton photoproduction are reported.

Yerevan Physics Institute

Yerevan 1980

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ФУНКЦИЯ ВОЗБУЖДЕНИЯ ФОТОРОЖДЕНИЯ КУМУЛЯТИВНЫХ  
ПРОТОНОВ НА ЯДРАХ

Приводятся новые экспериментальные данные по энергетической зависимости предэкспоненциальной постоянной  $C_p$  в представлении  $\rho = f/\sigma_t = C_p \exp(T/T_0)$  инвариантного нормированного сечения фоторождения кумулятивных протонов.

Ереванский физический институт

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1. In the processes of cumulative production of protons on nuclei by primary  $\pi^-$ -mesons and protons the asymptotical invariance of representation parameter  $C_p$  of the invariant normalized cross section

$$\rho = f/\sigma_t = C_p \cdot \exp(T/T_0) \quad (1)$$

with respect to the incident particles energy is observed <sup>[1]</sup>. In (1)  $C_p$  and  $T_0$  are representation parameters,  $T$  is kinetic energy of the detected particle,  $\sigma_t$  is total cross section of interaction of incident particle with target-nucleus. Whereas for the lightest nuclei (for example, for  $^{12}\text{C}$ ) this invariance is achieved at already 1.5 GeV, for heavy nuclei (such as  $^{208}\text{Pb}$ ) the same invariance is observed at relatively high energies (4 + 5 GeV). Following theoretical models according to which the cumulative protons are produced in the interaction of the incident particle with nuclear nucleons or other nucleon formations, one can explain such a behaviour of parameter  $C_p$  if taking into account the fact that primary hadrons interact with all the abovementioned objects in a tube with a radius equal to the hadron interaction radius. According to these representations in the case of more weakly interacting primary particles (electrons, photons, neutrino, etc.) the invariance  $C_p$  must be observed at same energies both for light and heavy nuclei since such incident particles interact in

the nucleus mainly once.

The properties of parameter  $C_p$  in the photoproduction of protons on nuclei by bremsstrahlung  $\gamma$ -quanta have been investigated in Refs [2, 3]. Of most importance in these properties is the difference of angular dependences for lightest and heavy nuclei. For example, for  $^{12}\text{C}$  with increasing the angle a noticeable decrease of  $C_p$  is observed, while for  $^{63}\text{Cu}$   $C_p = \text{const}$ , and for  $^{208}\text{Pb}$  there is a tendency of increasing  $C_p$  as  $\nu_p$  grows. Owing to this fact the presence of A-dependence ( $C_p \sim A^{1/3}$ ) is observed in the region of large angles. However the most important property of parameter  $C_p$  is its dependence on the primary  $\gamma$ -quanta energy.

As far as it is proved that parameter  $T_0$  in representation (1) is not a function of energy in the region  $(E_\gamma)_{\text{max}} \geq 2.0 \text{ GeV}$  [4], then instead of considering  $C_p$  dependence on primary energy, it is sufficient [1] to study the invariant normalized cross section dependence  $\rho(E_\gamma)$

In this work we give experimental dependences of the invariant normalized cross section (1) of cumulative protons produced by the energy of primary  $\gamma$ -quanta in the energy range of 2 + 4.5 GeV at the detection angle  $\nu_p = 120^\circ \pm 3^\circ$  and the secondary protons momentum  $P_p = (0.520 \pm 0.011) \text{ GeV}/c$  on nuclei  $^{12}\text{C}$ ,  $^{27}\text{Al}$ ,  $^{63}\text{Cu}$ ,  $^{118}\text{Sn}$  and  $^{208}\text{Pb}$ .

2. The experimental data are taken from the beam  $\Gamma$ -3 of the Yerevan electron synchrotron with the help of a "Deuteron" setup [5]. Protons were identified with a range telescope [6] which enabled to identify reliably the protons on the background of other particles in a solid angle  $\Delta\Omega = 10 \text{ milliradian}$ .

The reaction



where  $X$  is a residual system, was investigated.

Owing to the fact that the used  $\gamma$ -quanta beam has bremsstrahlung spectrum, the cross section of reaction (2) for the given value of  $\gamma$ -quanta energy  $E_\gamma$  can be determined (if the shape of the spectrum is known) by measuring the yields at two values  $(E_{\gamma 1})_{max}$  and  $(E_{\gamma 2})_{max}$ , so that

$E_{\gamma 1} \leq E_\gamma \leq E_{\gamma 2}$ . Assuming that  $\rho$  does not vary in the interval  $E_{\gamma 1} \div E_{\gamma 2}$  the unknown cross section is determined by the relation

$$\rho(E_\gamma) = (y_2 - y_1) / [\sigma_t^{\gamma A} \cdot \int_{E_{\gamma 1}}^{E_{\gamma 2}} (dN/dE_\gamma) dE_\gamma] \quad (3)$$

where  $y_1$  and  $y_2$  are invariant yields of reaction (2) at  $(E_{\gamma 1})_{max}$  and  $(E_{\gamma 2})_{max}$ , respectively;  $dN/dE_\gamma$  is  $\gamma$ -quanta difference spectrum;

$\sigma_t^{\gamma A}$  is total averaged cross section of photoabsorption in the interval  $E_{\gamma 1} \div E_{\gamma 2}$ .

This method of determining  $\rho$  is called the subtraction method. There is another [7], more precise, but much more complicated method to determine  $\rho(E_\gamma)$  by measured  $y_i$ , the so-called "reciprocal matrices method". In this work we give the results obtained by the subtraction method, i.e. by formula (3).

Of most importance in the subtraction process are the problems of errors and contribution of the low-energy part of  $\gamma$ -quanta spectrum. To take the latter into account let us consider the  $\gamma$ -quanta difference spectrum with two close values of  $(E_\gamma)_{max}$ . These spectra for three differences with the interval of 0.5 GeV are shown in fig.1. As one can see, the difference spectrum indicates the presence of finite number of  $\gamma$ -quanta in the low- $E_\gamma$  region. However, since the integral number of these low-energy photons does not exceed 5% of the peak in the  $(E_\gamma)_{max}$ , we neglect their contribution [8]. As to the errors, here, first, measures were

taken to decrease at most both statistical and systematical errors which in this measurement run have been reduced to  $\pm(1 + 2)\%$  and  $\pm(1.5 + 2)\%$ , respectively, therefore total errors did not exceed  $\pm 3\%$ ; and second, the known smoothing method was used [7]. For that the invariant (non-normalized) yields  $Y = Y[(E_\gamma)_{\max}]$  for the given nucleus were fitted by the least squares method with the best by criterion  $\chi^2$  curves. It was assumed that the curve between the neighbour values of  $(E_\gamma)_{\max}$  has no singularities. The results of these procedures are given in fig.2. The experimental points are marked, the curves are calculated by formula

$$Y = \sum_{i=0}^2 a_i \cdot (E_\gamma)_{\max}^i \quad (4)$$

where coefficients  $a_i$  are determined by experimental points. Thus it is possible to draw smoothly rising over  $(E_\gamma)_{\max}$  curves through experimental points for all the nuclei. One can claim that in the first approximation none of the investigated nuclei has anomalously high yield growth.

To determine dependences  $\rho = \rho(E_\gamma)$  we have determined the differences  $Y[(E_{\gamma 2})_{\max}] - Y[(E_{\gamma 1})_{\max}]$  by the curves of fig.2 (but not by experimental points) and using the data on total cross sections  $\sigma_t^{IA}$  of hadronic photoabsorption on nuclei [9] we have defined  $\rho(E_\gamma)$  by (3). The results are shown in fig.3. The errors include the contributions of statistical and systematical spreads of experimental measurements as well as the errors in approximation of the corresponding curves. The width of a "step" near a point is determined by subtraction interval.

According to fig.3 the normalized cross section  $\rho(E_\gamma)$  becomes invariant under primary energy in the region of 4 GeV for heavy nuclei as it is the case in the hadron processes. As to light and lightest nuclei, here low growth of  $\rho(E_\gamma)$  is observed in the investigated  $E_\gamma = 2 + 4.5$  GeV region, i.e. invariance is not yet achieved. So new measurements at high

primary energies ( $E_{\gamma} > 4.5$  GeV) are obviously needed.

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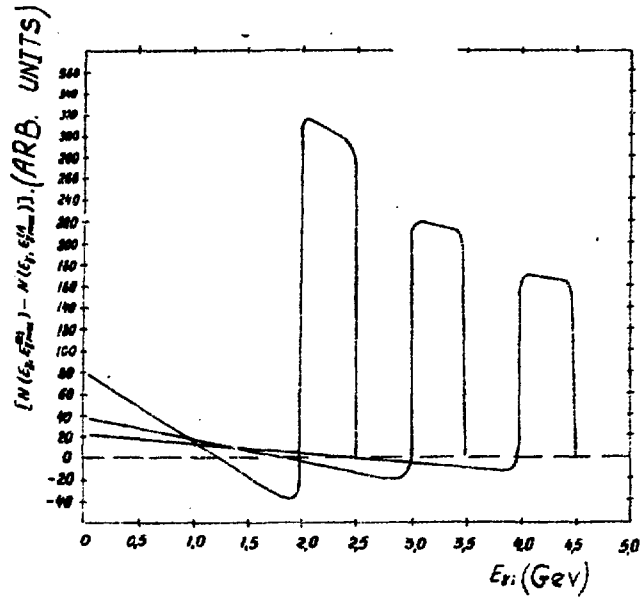


Fig.1

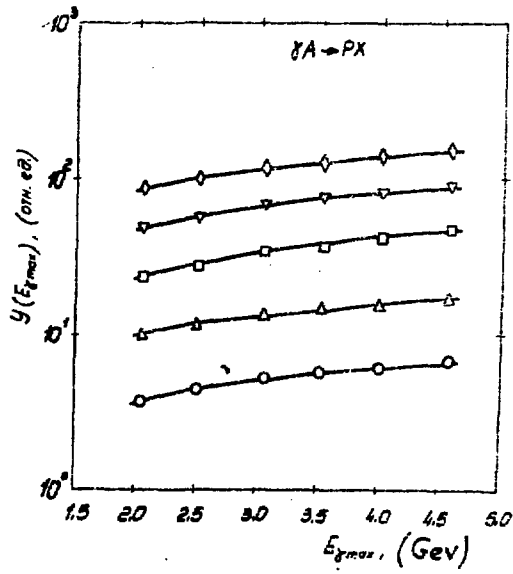


Fig.2

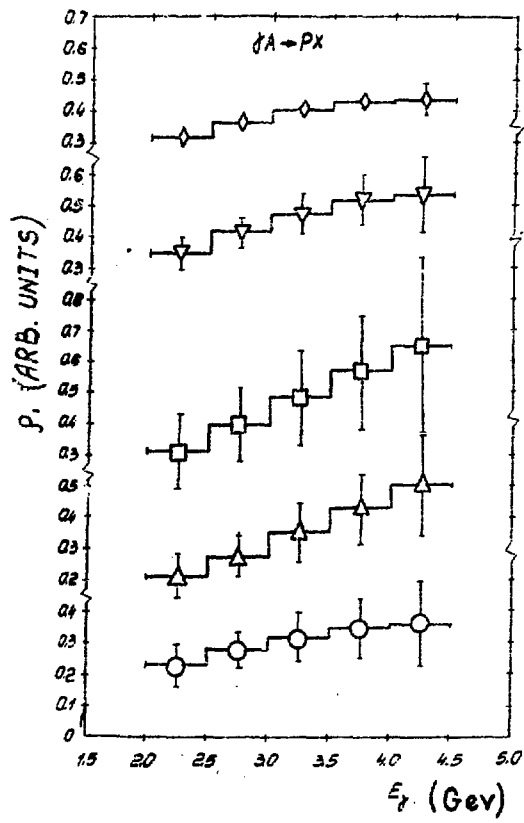


Fig.3

CAPTIONS

Fig.1  $\gamma$ -quanta difference spectra for  $(E_{\gamma 2})_{max}$  and  $(E_{\gamma 1})_{max}$ , respectively: 1.- (2.5 and 2.0) GeV, 2.- (3.5 and 3.0) GeV, 3.- (4.5 and 4.0) GeV.

Fig.2 Dependence of invariant cross section (2) on the maximum energy of bremsstrahlung  $\gamma$ -quanta  $(E_{\gamma})_{max}$ . Experimental points:  $\square$  - C,  $\triangle$  - Al,  $\square$  - Cu,  $\nabla$  - Sn,  $\diamond$  - Pb. The curves are drawn by (3) (see the text).

Fig.3 Dependence of invariant normalized cross section  $\rho(E_{\gamma})$  on  $\gamma$ -quanta energy. Experimental points: the same as in fig.2.

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