Subthreshold production of K^+ mesons by protons in the energy range 800–1000 MeV at the Be, C, Cu, Sn, and Pb nuclei

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(Submitted 3 February 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **43**, No. 5, 214–216 (10 March 1986)

The experimental data on the total cross sections for the production of K^+ mesons in the interaction of protons in the energy range $T_p = 800$–1000 MeV with Be, C, Cu, Sn, and Pb nuclei have been obtained for the first time. These data are compared with the predictions of different models.

The study of the reactions involving the subthreshold production of particles (antiprotons, Π mesons, K mesons) in the interaction of protons with nuclei at incident-proton energies much lower than the reaction threshold in free nucleon-nucleon interactions may be one possible method of obtaining information about the high-momentum component of the intranuclear motion of nucleons and short-range multinucleon correlations in nuclear matter. The principal advantage of the reactions involving the production of K^+ mesons is the weak interaction of low-energy K^+ mesons with the nuclear medium.

The measurement method has already been described by us elsewhere.[1–3] This method can be summarized as follows. A proton beam strikes a meson-producing target in which the K^+ mesons are produced and stopped. The size of the target is chosen in such a way that all K^+ mesons with energies $T_K \leqslant 70$ MeV produced at the center of the target would be stopped. The intensity of the proton beam of the synchrocyclotron of the Leningrad Institute of Nuclear Physics is distributed periodically with respect to time in the form of short (5-ns) microbunches with a period of 75 ns. Consequently, the K^+ mesons are produced and stopped at discrete moments of time with a period of 75 ns, while the partial decay of the K^+ mesons which are stopped in the target occurs between the proton microbunches. The monoenergetic μ^+ mesons ($P = 236$ MeV/c) from the $K \to \mu\nu$ decay are removed by means of a magnetic spectrometer ($\Delta P/P = 5\%$, $\theta = 60°$) and detected in a 40-ns time window in the time interval between the microbunches when the background of the μ^+ mesons from $\pi \to \mu\nu$ decay is no greater than 1–5% of the effect. The normalization was carried out on the basis of the yield of the Π^+ mesons whose production cross sections are known.[4]

The systematic error in the measurement of the absolute values of the total cross sections is no greater than 20%. The results of the measurements are shown in Figs. 1 and 2 in which only the statistical errors are indicated.

At proton energies below 1000 MeV, the production of K^+ mesons has the fol-

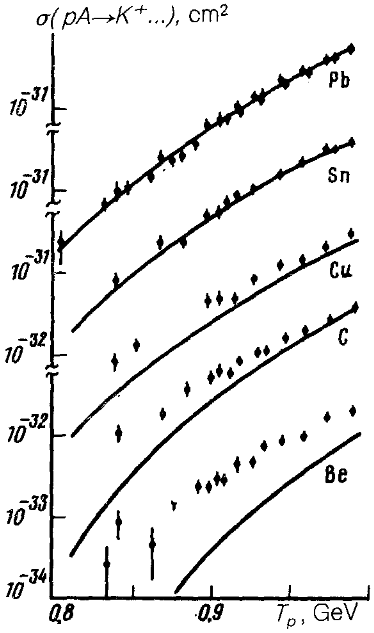

FIG. 1. The energy dependence of the total cross sections for the production of K^+ mesons compared with the calculations based on the mean-field model.

lowing particular feature: If the process occurs in a single interaction of an incident proton with a single or a group of correlated nuclear nucleons, then the momentum of the nuclear nucleon in these reactions must be large on the nuclear scale or the interaction must occur with a group of more than three nucleons (Fig. 2).

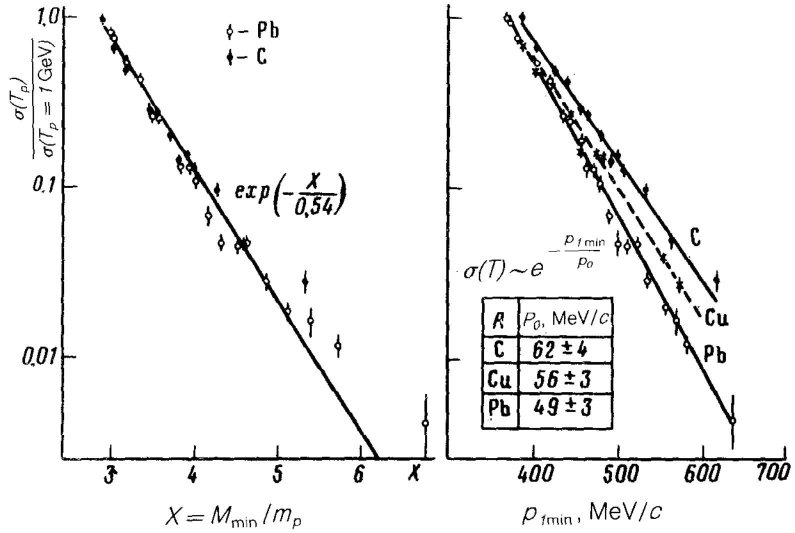

FIG. 2. The total cross sections for the production of K^+ mesons versus the minimum mass of a group of nuclear nucleons (M_{min}) and versus the minimum momentum of a nuclear nucleon ($P_{1\ \text{min}}$) which corresponds to the reaction threshold.

In terms of a single interaction with the nucleons of the nucleus (or with a group of nuclear nucleons) the cross section for subthreshold production of K^+ mesons can be calculated on the basis of the equation

$$\sigma^{tot} = N_{\mathrm{eff}} \; W_{nN} \int_{P}^{\infty} \sigma_{pN \to K} \, \rho_n (P_{nN} ; \; \epsilon) \, d^3 P_{nN} ,$$

where $\sigma_{pN \to K}$ is the total cross section for production of K^+ mesons in pN interactions. On the basis of the experimental data of Ref. 10 the behavior of this cross section near the threshold can be described as follows: $\sigma_{pN \to K} = 26 \times 10^{-30} (S - S_0)^2$, cm^2.

Most models differ from each other in the choice of the specific form of the spectral function ρ_n, in the kinematics of the process (S, S_0), in the method of determining the probability for the production of a group of nucleons in the superdense state in the nucleus (W_{nN}), and in the effective number of nuclear nucleons N_{eff}. If we assume that $n = 1$, then $W_{1N} = 1$, and N_{eff} can be calculated by using the Glauber model ($N_{\mathrm{eff}} = 66$, 44, 28, 7.3, and 6.3 for ^{208}Pb, ^{119}Sn, ^{64}Cu, ^{12}C, and ^{9}Be nuclei, respectively, at an energy $T_p = 1000$ MeV).

Without using the short-range correlations, we can calculate ρ_1 by using the Hartree-Fock model with Skyrme's effective forces. The momentum distribution at large momenta obtained in this manner is given by $\rho_1(P) \sim \exp(-2\pi a P)$, where a is the spatial diffusivity of the edge of the nucleus. The spectral function calculated in this manner makes it possible to satisfactorily describe the energy dependence of the total cross sections. The absolute values of the calculated cross sections, however, turn out to be lower than the experimental values by a factor of 1000. It is very difficult to correctly determine the short-range correlations in the Hartree-Fock model without the introduction of additional free parameters.

A fairly simple calculation of the short-range correlations was carried out in Ref.

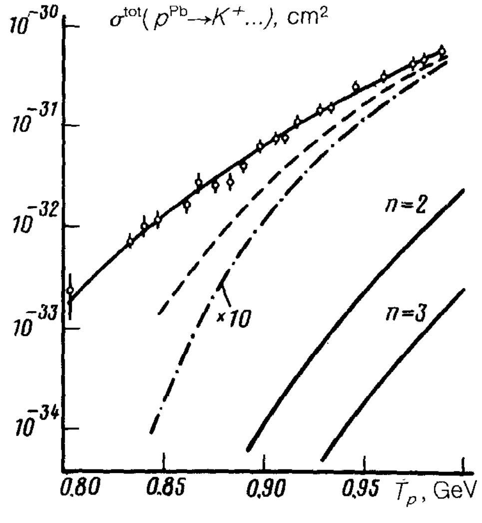

FIG. 3. Comparison of the experimental data with the results of the calculations based on the following models: mean-field model[6] (solid curve); flucton model[10] ($n = 2, n = 3$); color-string model[11] (dashed curve); spectator model[5] (dot-dashed curve).

5. The results of a calculation based on this model is shown in Fig. 3. The results obtained on the basis of this model are at variance with the experiment, both in the energy dependence and in the absolute values of the cross sections. The reason for this discrepancy apparently stems from the fact that the authors of Ref. 5 have correctly calculated the effect of only the two- and three-nucleon stationary correlations, whose contribution is zero in our case.

The mean-field model[6] was used to analyze the effective phenomenological spectral function in the form of a diffuse Fermi step:

$$\rho(P) = \rho_0/\{1 + \exp[(P - P_F)/P_D]\}.$$

The value of ρ_0 was found from the normalization condition $\int_0^\infty \rho d^3P = 1$; $P_D = 1/(2\pi a)$, and P_F and a were taken from Refs. 7–9. A comparison of the results of calculations, in which the effective spectral function was used, with the experimental data is shown in Fig. 1. Although the calculations were carried out without any additional normalization, the quantitative description of the experimental data is nonetheless quite good. A discrepancy is observed only for light nuclei.

The superdense states can be considered in the context of the flucton model[10] or the color-string model.[11] A calculation based on the color-string model, in which the motion of the nuclear nucleons in the octed tube is ignored (Fig. 3), does not describe the energy behavior of the total cross sections. The next step which was suggested by the authors of Ref. 11 and which involves a pulsed motion of a group of nucleons in the nuclei will considerably improve the description of the energy dependence of the cross sections, but at the same time it will complicate the determination of the absolute values of the cross sections, since this model does not predict the magnitude of the contribution from the individual tubes which include a different number of nucleons.

The probability for the formation of a superdense group (W_{nN}) can be determined by means of the flucton model.[10] This probability is so small ($W_{4N} \sim 10^{-5}$) that the cross sections calculated by means of the flucton model turn out to be considerably smaller than the experimental cross sections (Fig. 3; $n = 2,3$).

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Translated by S. J. Amoretty