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ON THE CHARACTERISTICS OF THE PARTICLE PRODUCTION PROCESS IN HADRON-NUCLEUS COLLISIONS: MULTIPLICITIES AND DISPERSIONS

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1. INTRODUCTION

The aims of the present paper are:

1. to calculate multiplicities, i.e. the mean numbers of particles produced in hadron-nucleus collisions and dispersions of these mean numbers, assuming as the basis the free-parameterless model of Z.Strugalski[1-6];

2. to compare the results of calculation with available experimental data.

This work is the continuation of our former paper[7] (henceforth citied as I), dealing with the ratio R_A between the mean number of charged particles created in hadron-nucleus collisions and the mean number of charged particles created in collisions of this hadron with the nucleon. The hadron-nucleus collisions are here analysed in the same energy ranges in laboratory system as in I, namely for 16-147 GeV/c for pion-nucleus collisions and for 19-1480 GeV/c for proton-nucleus collisions; the multiplicities are calculated for the same 24 nuclear targets (from $^{12}_{6}C$ to $^{238}_{92}U$) as in I, the dispersions are calculated for ten elements $^{12}_{6}C$, $^{22}_{13}Al$, $^{56}_{26}Fe$, $^{64}_{29}Cu$, $^{80}_{35}Br$, $^{108}_{47}Ag$, $^{151}_{54}Xe$, $^{184}_{74}W$, $^{207}_{82}Pb$, $^{238}_{92}U$.

2. CALCULATIONS OF THE MULTIPLICITIES OF PARTICLES AND OF THE DISPERSIONS

According to Strugalski's free-parameterless model the mean numbers of produced charged particles in high-energy hadron-nucleus collisions are given by

$$\langle n_{ch}(E_h)\rangle_{hA} = \langle m\rangle \langle n_{ch}(\frac{E_h}{\langle m\rangle})\rangle_{hN} , \qquad (1)$$

where $\langle n_{ch}(E_h)\rangle_{hA}$ is the mean number of charged particles produced in hadron-nucleus collisions at the energy E_h of the incident hadron in Lab., $\langle n_{ch}(E_h/\langle m\rangle)\rangle_{hN}$ is the mean number of particles produced in hadron-nucleon collisions at the energy $E_h/\langle m\rangle$; here $\langle m\rangle = e^t$, $t = \langle\lambda\rangle/\langle\lambda_0\rangle$, where $\langle\lambda\rangle$ is the mean thickness of nuclear matter (in nucleons per fm^2), taken from the paper of Strugalski and Pawlak[8], $\langle\lambda_0\rangle = k/\sigma_0$ is the mean free path of the hadron in nuclear matter for the particle producing collisions; k = 3 (see Strugalski [9]) and the values of σ_0 were taken from CERN-HERE tables[10].

The physical meaning of the quantity $<m>$ is as follows: According to the free-parameterless model [1] particles are created in those quasi-two-body hadron-nucleon (especially nucleon-nucleon) collisions, which produce two intermediate objects of the life-time long enough to be able to collide with the downstream nucleons in the target and to produce in this way new intermediate objects. As the result an almost one-dimensional cascade of intermediate objects is formed inside nuclear matter. The quantity $<m>$ is simply the mean number of particle producing collisions of the incident hadron together with the collisions of all the intermediate objects in the target nucleus.

The dependence of $<n_{ch}(E_h)>_{pN}$ on the energy of incident pions and protons, taken from CERN-HERA tables [10] and Goldschmidt-Clermont data [11] was presented in Fig.2 of I.

The dispersion D of the mean value $<n_{ch}(E_h)>_{hA}$, given by expression (1), is composed of two parts D_1 and D_2:

$$D^2 = D_1^2 + D_2^2, \tag{2}$$

where D_1 is the dispersion of the mean value $<n_{ch}(E_h/<m>)>_{hN}$ and D_2 is the dispersion of the quantity $<m>$.

The quantity D_1 is given as

$$D_1 = A_h\{<n_{ch}(E_h/<m>)>_{hN} - 1\}\sqrt{m}, \tag{3}$$

where according to Wroblewski [12]: $A_h = 0.576 \pm 0.008$ for p-p collisions between 4-303 GeV/c, $A_h = 0.44$ for π^-p collisions between 4-25 GeV/c and $A_h = 0.576$ for π-p collisions between 50-205 GeV/c.

The quantity D_2 is given by

$$D_2 = \tilde{D}(<m>) \cdot <n_{ch}(E_h/<m>)>_{hN}, \tag{4}$$

where

$$\tilde{D}^2(<m>) = <m^2> - <m>^2 = \sum_{m=1}^{R_t} m^2 <m>^{-1}\{1 - <m>^{-1}\}^{m-1} - <m>^2, \tag{5}$$

R_t is the distance (in nucleons/fm^2) from the center of the nucleus to its concentrical layer, where the average number of protons in the cylindrical volume $\pi D_0^2\lambda$ fm^3 is equal to 0.25 (D_0 is proton's diameter in fm). The values of R_t were taken from the paper of Strugalski and Pawlak [8].

3. RESULTS OF CALCULATIONS

The values of the mean numbers of produced charged particles in pion-nucleus collisions for 24 elements between $^{12}_{6}C$ and $^{238}_{92}U$ in the momentum range of incident pions in Lab. from 16 GeV/c to 147 GeV/c are given in Table 1, the values of the same quantity for proton-nucleus collisions at projectile momen-

Table 1

The multiplicities $<n_{ch}(p_\pi)>_{\pi A}$ of charged particles produced in pion-nucleus collisions, calculated using formula (1); p_π is the incident pion momentum in Lab. A denotes the charged nucleus

A / P_π	16.0	18.5	50	147
C	4.9	5.1	6.9	8.7
N	4.9	5.1	6.9	8.7
O	4.9	5.3	7.1	8.6
F	5.1	5.3	7.2	9.0
Ne	5.1	5.3	7.2	8.8
Al	5.1	5.4	7.2	9.1
Si	5.1	5.5	7.2	9.2
S	5.2	5.5	7.4	9.4
Ar	5.3	5.5	7.5	9.6
Cr	5.5	5.6	7.7	9.9
Fe	5.6	5.7	7.9	10.1
Co	5.5	5.7	7.9	10.1
Cu	5.6	6.0	8.1	10.3
Zn	5.6	6.0	8.1	10.3
Ge	5.7	5.7	8.2	10.5
Br	5.8	5.8	8.6	10.7
Ag	6.1	6.1	8.6	11.2
I	6.2	6.2	8.9	11.7
Xe	6.6	6.6	9.0	11.8
Ta	6.6	7.1	9.7	11.7
W	6.5	7.1	9.5	12.7
Au	6.6	7.2	9.7	13.1
Pb	6.7	7.2	9.7	13.1
U	6.9	7.4	10.1	13.6

ta between 19 and 1480 GeV/c in Lab. are given in Table 2. The corresponding dispersions for 10 elements from $^{12}_{6}C$ to $^{238}_{92}U$ in the same energy ranges of incident pions and protons as before are given in Table 3.

By inspection of these tables we can state that:

1. The mean values of the numbers of charged particles produced in hadron-nucleus collisions increase regularly and slowly with increasing target mass number A of about 50% for pion-nucleus collisions and of about twice for proton-nucleus collisions for targets from $^{12}_{6}C$ to $^{238}_{92}U$ at constant energy value.

Table 2

The multiplicities $\langle n_{ch}(p_p)\rangle_{pA}$ of charged particles produced in proton-nucleus collisions, calculated using formula (1); p_p is the incident proton momentum in Lab. A denotes the target nucleus.

A/P_p	19	24	32	60	102	205	290	405	500	1070	1480
C	5.2	5.8	6.3	7.6	8.6	9.8	10.5	11.3	11.7	13.4	14.1
N	5.3	5.9	5.4	7.7	8.7	10.0	10.8	11.6	12.0	13.7	14.6
O	5.4	5.9	6.4	7.8	8.8	10.2	10.9	11.7	12.1	13.9	14.7
F	5.4	6.1	6.5	8.0	9.1	10.4	11.4	12.1	12.6	14.5	15.3
Ne	5.4	6.1	6.5	8.0	9.1	10.4	11.4	12.1	12.5	14.3	15.2
Al	5.6	6.3	6.8	8.4	9.4	11.0	11.7	12.7	13.3	15.2	16.1
Si	5.7	6.3	6.8	8.4	9.4	11.0	11.8	12.7	13.3	15.3	16.2
S	5.7	6.5	7.0	8.5	9.6	11.2	12.0	13.0	13.6	15.9	16.5
Ar	5.9	6.6	7.4	8.8	10.1	11.9	12.7	13.8	13.9	16.3	17.7
Cr	6.1	6.7	7.6	9.0	10.6	12.4	13.3	14.5	14.6	17.3	18.5
Fe	6.2	6.9	7.7	9.1	10.7	12.6	13.5	14.6	15.3	17.8	18.8
Co	6.2	6.9	7.8	9.4	10.7	12.6	13.7	14.7	15.4	17.9	19.0
Cu	6.5	7.2	7.8	9.6	11.2	13.1	14.0	15.0	16.1	18.4	19.6
Zn	6.5	7.2	7.8	9.7	11.2	13.1	14.0	15.0	16.1	18.4	19.6
Ge	6.7	7.4	8.0	10.0	11.5	13.4	14.4	15.6	16.5	20.0	20.5
Br	6.8	7.5	8.1	10.2	11.4	13.4	14.3	15.4	16.9	19.5	19.8
Ag	7.1	7.8	8.9	11.0	12.6	14.8	16.1	17.2	18.1	21.6	22.8
I	7.1	8.1	9.0	11.7	13.3	15.8	16.8	18.4	19.4	23.1	24.2
Xe	7.5	8.2	9.1	11.9	13.4	15.9	18.3	18.7	19.6	23.1	24.7
Ta	7.9	9.0	9.9	12.9	14.6	17.8	18.9	20.9	21.8	26.4	26.4
W	7.9	9.0	10.0	13.0	14.6	17.8	18.9	21.0	21.9	26.4	28.5
Au	8.0	9.0	10.0	13.2	14.9	18.2	19.5	21.4	21.6	27.1	29.3
Pb	8.0	9.1	10.0	13.4	15.3	18.5	20.0	21.7	22.6	27.4	29.4
U	8.4	9.6	10.5	14.2	19.5	19.5	21.1	23.2	24.5	29.6	31.5

2. For each nucleus used as target the mean number of produced charged particles increases about two times in the momentum range 16-147 GeV/c of incident pions and about three times in the momentum range 19-1480 GeV/c of incident protons.

3. The dispersions in the above-mentioned hadron-nucleus collisions change also regularly and slowly. For each considered momentum of incident pion they change from C to U about two times, for incident protons even slower - about 50%.

4. For each considered target nucleus the dispersion increases with growing momentum of incident particles (in the above-mentioned momentum ranges): for incident pions about 2.5 times, for incident protons about three times; the rate of increase is smaller for heavier elements. For the heaviest elements and protons above 1000 GeV/c the dispersion shows even a small decrease.

Table 3

Dispersions D of the multiplicities of produced particles in pion-nucleus collisions, calculated using formulae (2)-(5); P is the projectile momentum in Lab. A denotes the charged nucleus.

	$\pi - A$			$p - A$				
A/P_h	16	50	147	19	102	405	1070	1480
C	2.4	4.1	5.5	3.0	5.1	7.0	8.8	8.7
Al	2.8	4.5	5.9	3.5	5.9	8.2	9.8	10.3
Fe	3.2	5.0	6.6	3.9	6.9	9.5	11.3	11.8
Cu	3.3	5.5	7.0	4.1	7.3	9.8	11.6	12.1
Br	3.5	6.1	7.9	4.2	7.9	10.2	12.0	12.5
Ag	3.9	6.1	7.9	4.5	7.9	10.9	12.6	12.7
Xe	4.0	6.2	8.2	4.7	8.0	11.1	12.5	12.9
W	4.0	6.8	9.3	4.6	8.1	11.1	11.5	11.8
Pb	4.1	7.0	9.5	4.6	8.7	10.9	11.3	11.0
U	4.6	7.4	10.1	4.7	8.5	10.8	9.1	9.2

4. COMPARISON WITH EXPERIMENTAL DATA

Some of the predictions of the free-parameterless model obtained in our calculations were compared with appropriate experimental data and are presented in Figs.1-4. Predictions given by the model agree well with corresponding experimental data. The model reflects well the energy- and A-dependences of produced particles and of their dispersions.

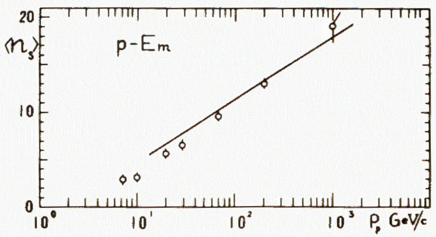
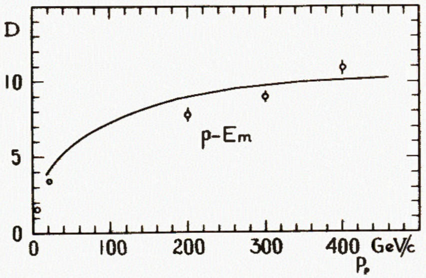
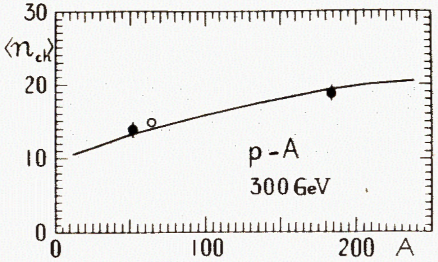


Fig. 1. Multiplicities $\langle n_s\rangle \equiv \langle n_{ch}\rangle$ of produced "shower" particles for proton-nucleus collisions in emulsions at various momenta p_p in Lab. of the projectiles. Solid line - calculations, open circles - compiled data from the work of A. Gurtu et al. /13/.

Fig.2. Dispersions D of the multiplicities of produced "shower" particles for proton-nucleus collisions in nuclear emulsions at various momenta p_p of the projectiles. Solid line - calculations, open circles - complied data from the work of Tsai Chü et al.[14].





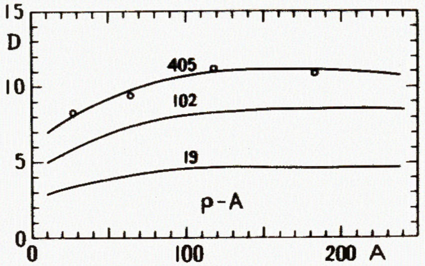


Fig.3. A -dependence of the multiplicity $\langle n_{ch} \rangle$ of produced particles in proton-nucleus collisions at 300 GeV/c. Solid line - calculations, black points - experimental data from the work of J.R.Florian et al.[15]; open circle - experimental information from the work of Tsai Chü et al.[14].

Fig.4. A -dependence of the dispersions D of the multiplicities of charged particles produced in proton-nucleus collisions at various projectile momenta in Lab. Solid lines - calculations, above the curves the incident proton momenta are given; open circles - experimental data from F. Fumuro et al.[16] at 400 GeV/c incident proton momentum.

REFERENCES

1. Strugalski Z. JINR, E1-82-401, Dubna, 1982.
2. Strugalski Z. JINR, E1-81-154, Dubna, 1981.
3. Strugalski Z. JINR, E1-81-155, Dubna, 1981.
4. Strugalski Z. JINR, E1-81-156, Dubna, 1981.
5. Strugalski Z. JINR, E1-81-576, Dubna, 1981.
6. Strugalski Z. JINR, E1-81-577, Dubna, 1981.
7. Sredniawa B., Strugalska-Gola E. JINR, E1-83-277, Dubna, 1983; also Proc. XVIII Cosmic Ray Conf., Bangalore, August 1983, vol. 5, HE/3/14, p. 160.

8. Strugalski Z., Pawlak T. JINR, E1-81-378, Dubna, 1981.
9. Strugalski Z. JINR, E1-83-378, Dubna, 1983.
10. Famino V. et al. CERN-HERA 79-01, 79-02, 79-03, 1979.
11. Goldschmidt-Clermont Y. Acta Physica Polonica 1973, B4, p. 805.
12. Wroblewski A. Proc. of the III Internat. Colloqium on Many-Body Reactions, Zakopane 1972, p. 140; Warsaw Univ. Preprint IFD 172/2; Acta Physica Polonica 1973, B4, p. 857.
13. Gurtu A. et al. Pramana, 1974, 3, p. 315.
14. Tsai-Chü et al. Nuovo Cim.Lett., 1977, 20, p. 257.
15. Florian J.R. et al. Phys.Rev.D, 1976, 13, p. 558.
16. Fumuro et al. Nucl.Phys., 1976, B152, p. 376.

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О характеристиках процесса рождения частиц в столкновениях адрон-ядро: множественности и дисперсии

Множественности, т.е. средние числа рожденных частиц в столкновениях адрон-ядро и дисперсии средних множественностей вычислялись в рамках модели Стругальского. Вычислены энергетические- и А-зависимости множественностей для 24 ядерных мишеней от $^{12}_{6}C$ до $^{238}_{92}U$ для пион-ядерных столкновений при 19 ÷ 147 ГэВ/с и для протон-ядерных столкновений при 19 ÷ 1480 ГэВ/с. Значения множественностей содержатся между 4,9 и 13,6 для пион-ядерных столкновений и между 5,2 и 31,5 для протон-ядерных столкновений. Дисперсии рассчитаны для 10 ядер между $^{12}_{6}C$ и $^{238}_{92}U$ в таком же диапазоне энергии и меняются от 4,2 до 10,1 для пион-ядерных и от 3,0 до 11,0 для протон-ядерных столкновений. Имеется хорошее согласие с экспериментальными данными.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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On the Characteristics of the Particle Production Process in Hadron-Nucleus Collisions: Multiplicities and Dispersions

Multiplicities, i.e., the numbers of particles produced in hadron-nucleus collisions and dispersions of these mean numbers are calculated assuming the free-parameterless model of Strugalski. Energy- and A-dependence of multiplicities are calculated for 24 nuclei from $^{12}_{6}C$ to $^{238}_{92}U$ for pion-nucleus collisions in the range 16-147 GeV/c and for proton-nucleus collisions between 19 and 1480 GeV/c. Multiplicities are comprised between 4.9 and 13.6 for pion-nucleus collisions and between 5.2 and 31.5 for proton-nucleus collisions. The dispersions of multiplicities are calculated for 10 elements between $^{12}_{6}C$ and $^{238}_{92}U$ in the same energy ranges and vary from 4.2 to 10.1 for pion-nucleus collisions and from 3.0 to 11.0 for proton-nucleus collisions. The agreement with available experimental data is good.

The investigation has been performed at the Laboratory of High Energies, JINR.

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