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Implementation of a thermodynamic formula of nucleus-nucleus collisions in eas data analysis

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Abstract A thermodynamic description of nucleus interactions is made on the basis of recent accelerator data. The thermodynamic formula for the momentum spectra of the secondary mesons in p-p collisions, e^+e^- annihilation and DIS is adjusted for nucleus collisions. It allows extrapolating accelerator data to the high-energy region of the EAS in cosmic rays. A precise parametrisation of the fragmentation properties is derived for estimation of the mass composition of primary cosmic rays on the basis of EAS data.

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1. Introduction

Boltzmann statistics for free particles leads to too fast energy rise of the multiplicity revealing correlations. It is needed to apply a thermodynamic or hydrodynamic approach. The thermodynamics can be applied for the final state (or earlier if the time of correlations is less then the time of interactions, e. g. when the Lorentc factor is less then $(M/m)^2$, M and m is the mass of the interacting and created particles respectively). The relativistic hadron thermodynamic should take into account the both important facts: for the small transverse momentum of created hadrons (by separating the Boltzmann terms to two parts) and for the less value (than 0.25) of the power index α in the energy dependence of the multiplicity. The latter varies between 0.13 and 0.22 in the range of the accelerator experiments with proton-proton collision, electron-positron annihilation and deep inelastic scattering of leptons (G. Kamberov(1999)). Such a parametrisation can be adjusted for nucleus collisions using a geometrical approximation that can be used in the study of the extensive air showers of cosmic rays.

2. Results

In fact recent data (Aguire et al. (2000)) confirm the geometrical dependence of the inelastic cross section on the projectile mass A_P :

$$\sigma \propto A^{2/3}$$

A weak increase of the mean free path should be accounted according to the cosmic ray observations (Aguire et al. (2000)): $\sigma \propto A^{-0.63}$.

For the study of the EAS it is important to know the mass of the projectile fragments (we assume an equipartition of the projectile energy between its nucleons). Recent accelerator data (Aguire et al. (2000)) indicate that the projectile fragments bring a very big part of the energy (in contrary to the superposition model). One can expect that the projectile fragments create a great deal of shower particles. Their total mass increases with the projectile mass at power 2/3 (the fragment is considered as an unaffected part of the projectile that increases with the projectile radious but decreases with its surface).

In Table 1 we present the integral probability for the fragmentation of ^{16}O and ^{32}S colliding with emulsion at 200 GeV/nucleon estimated on the basis of the KLM data (Walter et al. (1999)). The target mass dependence is neglected.

Table 1

^{16}O

Fragment. mode	Probability P	$<A_F>$ a. u.	P $<A_P>$
No fragments	0.30	0	0
Only α	0.34	3.3	1.122
Frag. change $z \geq 3$	0.30	12.0	3.600

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$z \geq 3 + \alpha$	0.06	12.4	0.744
Average mass of ^{16}O fragments $<A_F> = 5.5$			
^{32}S			
No fragments	0.16	0	0
Only α	0.28	4.5	1.26
Frag. change $z \geq 3$	0.36	24.0	8.64
$z \geq 3 + \alpha$	0.23	26.0	5.98
Average mass of ^{32}S fragments $<A_F> = 16$			

The results in Table 1 confirm the expected $A^{3/2}$ dependence of the average fragment mass. Using this dependence we obtain for Fe $<A_F> \geq 29$ a. u.

In many experiments it was found that the average multiplicity of the created mesons is proportional to $A_P^{1/3}$. One should expect the same dependence for the number of the interacting nucleons,

$$N_{\text{int}} = 0.8 A_P^{1/3},$$

if the assumption of an equipartition of the energy is valid. In Table 2 we compare our calculations with the KLM results for the number of detected pions N_π and the number of charged shower particles with z = 1 and velocity $\beta > 0.7$ multiplied by 3/2 (here the created pions, spectator and the interacting protons are included). In the table there are presented the number of interacting N_{int} which is used to calculate the number of pions N_π from the multiplicity in p-p collisions. In the number of shower there are added the number of spectator and remaining protons after collisions in accord with the relation:

$$N_\pi = N_S - [z_P - < z_F >]$$

(z_P is the charge of the projectile).

Table 2

Projectile	$<N_S>$	$<N_\pi>$	N_{int}	N_π	N_S
p		13	1	13	14
^{16}O	63	58.4	4.5	58.5	63.75
^{32}S	87.8	79.5	6.0	78.0	86.0

This table confirms our assumption for an equipartition of the energy and the rules for calculation of the final particle number.

In Table 3 we compare our calculations for the average pseudorapidity $<\eta>$ with the experimental values for all shower particles in the same experiment. It is also shown the average energy of the shower particles:

$$< E > = \frac{200 N_{\text{int}}}{\frac{3}{2} N_S},$$

including the neutral. We assume 0.7 for the average transverse momentum accounting for the target effect and the participance of nucleons.

Table 3

Projectile	Experiment	Calculations	
	$<\eta>$	$<E>$	$<\eta>$
^{16}O	3.23±0.01	9.41	3.29
^{32}S	3.37±0.01	12.50	3.57
p	2.86±0.01		

The satisfactory agreement in Table 3 indicates that the momentum spectra of the created mesons in nucleus interactions are similar to those in p-p collisions well described by Boltzmann type distribution. Even more, the temperature is almost the same for given energy per nucleon. It explains the experimental observations (Walter et al. (1999)) that the mass of the projectile has no significant influence on the mean number of the target fragments N_b (it is a small number, about 8 ± 0.02). Assuming N_b as a measure of the target temperature our result explains why it is limited to a given value no matter how heavy is the projectile.

3. Conclusions

In conclusion we can mention that our calculations of EAS properties with the present parametrisation lead to very good agreement with the experimental data.

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