THE MAXIMUM DEPTH OF SHOWER WITH $E_o > 10^{17}$ eV ON AVERAGE CHARACTERISTICS OF EAS DIFFERENT COMPONENTS

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ABSTRACT

EAS development model independent method of the determination of a maximum depth of shower (X_m) is considered. X_m values obtained on various EAS parameters are in a good agreement.

1. Introduction. Investigations of the shower maximum depth X_m are carried out at various arrays and by different methods but the significant scattering of the obtained data is still available (Table 1). A reason of most of discrepancies is mainly due to methodical difficulties associated with the transition from the observed EAS parameters $P=P(X_m)$ to X_m. Thereby one had to use the theoretical conceptions on EAS development difficult to test experimentally.

2. Method. We considered one more method of X_m determination on the experimental data obtained at the Yakutsk EAS array. By computer calculations such parameters were found which are the functions of $P=P(X_m/X)$ or $P=P(X-X_m)$ type in wide limits of initial conditions: $X=1020\cdot\sec\theta$. The calculations were carried out at various E_0 and θ on two, quite different models of EAS development. The first model corresponded to scaling [10], the second one - to scaling at $E<10^{14}$ eV

Table 1

Parameter	E_o	X_m	Work
n_Q	$1,6\cdot10^{17}$	660±30	[1]
$\tau_{1/2}(Q)$	$1,4\cdot10^{17}$	700±15	[2]
	$2\cdot10^{17}$	681±20	[3]
	$1,2\cdot10^{17}$	706±36	[4]
	10^{17}	620±20	[5]
	10^{17}	545±20	[5]
	10^{17}	500±20	[5]
	$2\cdot10^{17}$	680±20	[6]
LDF(Q)	$2\cdot10^{17}$	627±20	[7]
	$1,5\cdot10^{17}$	600±50	[8]
$\Psi(\mu)$	$3\cdot10^{17}$	684±30	[9]
$lg(\rho_c/\rho_\mu)$	$3\cdot10^{17}$	750±30	[9]
LDF(ρ_c)	$3\cdot10^{17}$	609±3	[9]

[10] and to $n_s \sim E^{0,25}$ at $E \geq 10^{14}$ eV. The cross-sections in inelastic processes on both models changed with energy according to [10]. The index of the LDF of electrons n_e at the distance interval R=200–600 m from the shower core ($\rho_e \sim R^{-n_e}$) and ratios of densities of the EAS Cerenkov light to electrons $\lg(Q/\rho_e)$ and of electrons to muons $\lg(\rho_e/\rho_\mu)$ at R=300 m were considered. The above parameters are satisfactorily measured at the Yakutsk EAS array ($\rho_e = \rho_s - \rho_\mu$).

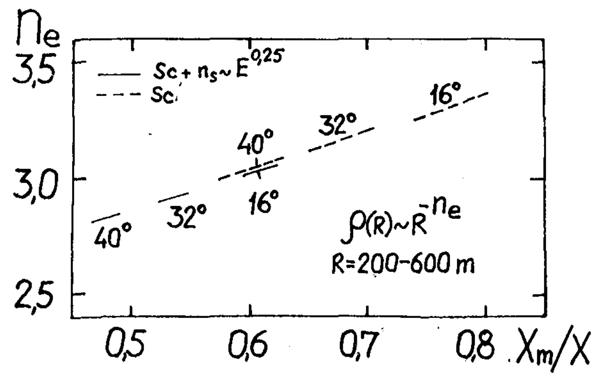

Fig.1

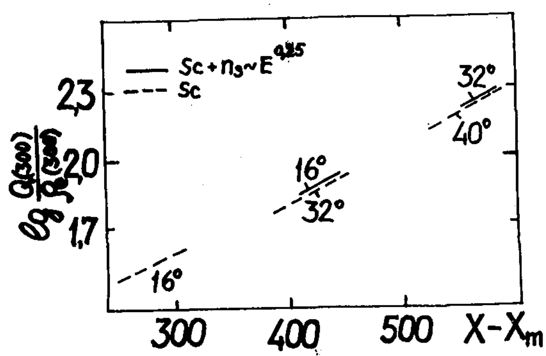

Fig.2

3. Results. Calculation results at $E_0 = 10^{17}$–10^{18} eV and Θ = 16, 32 and 40° are shown in Figs.1–3. From Fig.1 it is seen that n_e is unambigiously associated with X_m/X independently of E_0, Θ and characteristics of nuclear interactions. We use this peculiarity of electron LDF to find X_m:

$$X_m = \left(\frac{n_e - 2,11}{1,7}\right) \cdot X, \text{ g/cm}^2 . \qquad (1)$$

The obtained X_m are given in Table 2. The parameter $\lg(Q/\rho_e)$ which is the function of $X-X_m$ possesses the analogous feature (Fig.2).

$$X_m = X - 423\left(\lg\frac{Q}{\rho_e} - 0,88\right). \qquad (2)$$

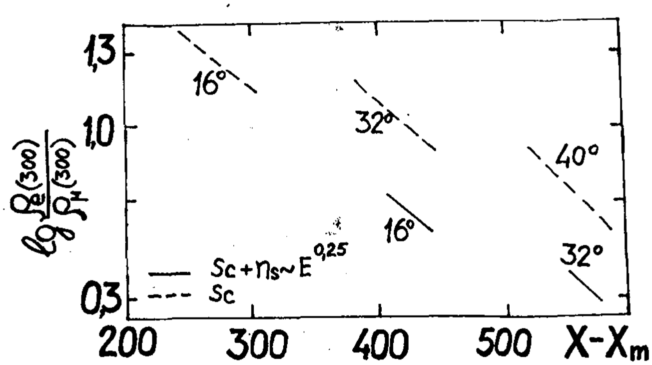

Fig.3

Table 2

lg E_0	17,20	17,55	18,02	18,42	18,94
X, g/cm^2	1060	1060	1070	1080	1060
n_Q	2,57	2,60	2,70	2,78	2,80
$X_m \pm \Delta X_m$	660±30	675±30	725±30	765±30	755±40
n_e	3,18	3,22	3,26	3,31	3,31
$X_m \pm \Delta X_m$	665±60	690±60	720±60	760±60	750±60
$\lg(Q/\rho_e)$	1,94	1,91	1,79	1,71	1,59
$X_m \pm \Delta X_m$	615±30	625±30	685±40	730±40	760±45
$\lg(\Phi/N_e)$	5,37	5,31	5,19	5,19	5,0
$X_m \pm \Delta X_m$	640±40	665±40	725±40	735±40	800±40
lg E_0	-	17,56	17,91	18,39	18,79
X, g/cm^2	-	1090	1080	1080	1080
$\lg(\rho_e/\rho_\mu)$	-	0,76	0,82	0,99	1,04
$X_m \pm \Delta X_m$	-	670±20	670±20	715±20	725±25
$\lg(N_e/N_\mu)$	-	1,17	1,28	1,47	1,54
$X_m \pm \Delta X_m$	-	665±35	670±35	720±35	735±35

As for $\lg(\rho_e/\rho_\mu)$ the unambiguity condition due to the zenith angle is broken. Therefore the experimental and calculational data are needed to be compared at similar Θ.

The averaging of data in Table 2 results in the following expression:

$$X_m = (700\pm35) + (66\pm6)(\lg E_0-18),\ g/cm^2. \qquad (3)$$

Note that all the above parameters were experimentally obtained at fixed $\rho_s(300)$ and calculations were also carried out under such condition. If to make calculations at fixed E_0, then X_m value becomes $\sim 50\ g/cm^2$ less.

4. Discussion. The integral values $\lg(\Phi/N_e)$ and $\lg(N_e/N_\mu)$ are close to the parameters $\lg(Q/\rho_e)$ and $\lg(\rho_e/\rho_\mu)$. Here Φ is the total flux of the EAS Cerenkov light; N_μ and N_e are the total numbers of muons and electrons. Their dependences on $X-X_m$ are analogous to ones presented in Figs.2 and 3.

Apply this method of the analysis of data to other arrays. One can do it without additional calculations with respect to the parameter $\lg(\rho_c/\rho_\mu)$ [9], since it is similar to our parameter. According to [9] at R=300 m, $E_0=10^{17}$ eV and $\Theta \approx 15°$ we have $\lg(\rho_c/\rho_\mu)=0,3$. To recount from ρ_c measured at the Haverah Park array to ρ_e at R=300 m we use the ratio $\rho_e / \rho_c \approx 1,8$ [11]. Then $\lg(\rho_e / \rho_\mu) \approx 0,58$ and from Fig.3 we find $X_m \approx 620$ g/cm^2, i.e. much higher than in Table 1.

5. Conclusion. The analysis of various EAS components based on the method of "model independent" parameters yields $X_m = 700 \pm 35$ g/cm^2 at $E_0 = 10^{18}$ eV and at fixed $\rho_s(300)$.

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