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# THE EXPERIMENTAL CASCADE CURVES OF EAS AT $E_0 > 10^{17}$ eV OBTAINED BY THE METHOD OF DETECTION OF CHERENKOV PULSE SHAPE

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Since recently we have systematically studied the individual cascade curves of EAS with $E_0 > 10^{17}$ eV /I-3/ by the method of detection of EAS Cherenkov light pulses proposed initially in /4/.

The scintillators located at the center of the Yakutsk EAS array within a 500-m radius circle were used to select the showers and to determine the main EAS parameters (the axis coordinates, the azimuthal and zenith angles $\varphi$ and $\theta$, and the primary energy $E_0$) /5/. The individual cascade curves N(t) were obtained using the EAS Cherenkov light pulses satisfying the following requirements: (I) the signal-to-noise ratio $f_m/\sigma_n \geqslant 15$, where $f_m$ is the amplitude of pulse, $\sigma_n$ is the r.m.s. value of night sky noises, (2) the EAS axis-detector distance $r_\perp \geqslant 350$ m, (3) the zenith angle $\theta \leqslant 30^\circ$, (4) the probability for EAS to be detected by scintillators $W \geqslant 0.8$. Condition (I) arises from the desire to reduce the amplitude distortion of Cherenkov pulses due to noise and determines the studied range of EAS sizes, N(t). The resolution times of the Cherenkov pulse shape detectors are $\tau_0 \simeq 23$ ns which results in distortion (broadening) of a pulse during the process of the detection. The restrictions $r_\perp \geqslant 350$ m and $\theta \leqslant 30^\circ$ permit to select the Cherenkov pulses with relatively high $\tau_{0.5}$ (the half-width of non-distorted pulses). We estimated the distortion of pulses due to the finiteness of $\tau_0$ value. It was shown that the rise time of pulse becomes greater as $\tau_{0.5}/\tau_0$ ratio decreases; at the same time the tail does not vary within 5% accuracy. The results were used in order to correct the experimental pulses.

Since the moment of intersection of the observation level and the EAS axis is not fixed experimentally, the Cherenkov pulse is measured on the scale of relative time $\tau$ . In order to determine the absolute time $\tau_A$ it is necessary to use the results of theoretical calculation /6/ which permit to find the difference of values $\tau_{mA}^N$ and $\tau_{mA}^f$ , where $\tau_{mA}^N$ is the time moment when the light corresponding to EAS maximum is detected and $\tau_{mA}^f$ is the time corresponding to the Cherenkov pulse maximum: $\Delta\tau_m(t_m, r_\perp) = \tau_{mA}^N(t_m, r_\perp) - \tau_{mA}^f(t_m, r_\perp)$, where $t_m$ is the EAS maximum depth in the atmosphere. The value of $t_m$ can be determined from the half-width $\tau_{0.5}$ of the given pulse /7/ and can be used to find $\tau_{mA}^N$ in accordance with formulae of /2,3/. Then one obtains the time $\tau_{mA}^f = \tau_{mA}^N - \Delta\tau_m$ corresponding to the maximum of experimental Cherenkov pulse. The theoretical functions /2,3/ used for the transformation of the Cherenkov pulse $f(\tau_A, r_\perp, \theta)$ to the cascade curve N(t) are independent, to within a 5% accuracy, on the adopted model of EAS development and the primary composition. This is illustrated by the function $\Delta\tau_m(t_m, r_\perp)$ shown in Fig. I for the high-multiplicity model (HMM) and for the quark-gluon strings (QGS) model for a primary proton (A=I) and a primary iron nucleus (A=52) /6,8/. These functions depend only on the angle distribution of EAS electrons /7/.

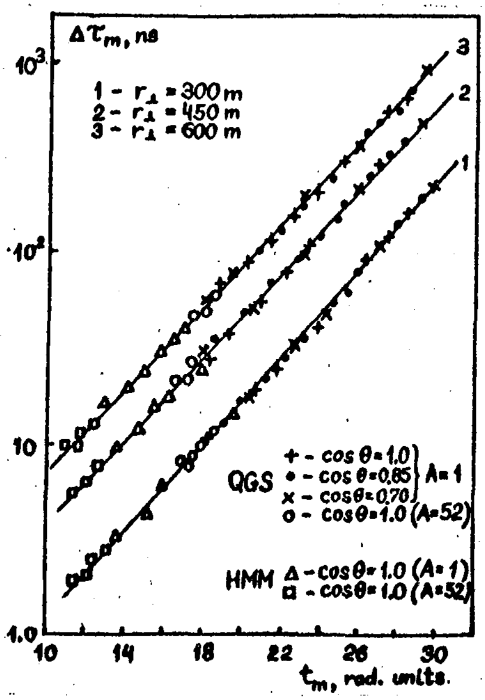


Fig. I

26 showers with Cherenkov pulses satisfying to above men-

tioned requirements were selected. It should be noted that IO showers out of 26 exhibited the Cherenkov pulses in two detectors at different distances from EAS axis under condition $f_m/\sigma_n \geq 15$. For these events the r.m.s. errors $\sigma_m = \sqrt{D(t_{m_I} - t_{m_2})}$ = I.2 radiation units, where $t_{m_1}$ and $t_{m_2}$ are depths of EAS maximum determined from two Cherenkov pulses. The errors $\sigma_{0.25}$ for the depths corresponding to the points on the ascending branch of the cascade curve at the 0.25 $N_m$ level ($N_m$ is the EAS size in the maximum) $(t_{0.25})_I$ and $(t_{0.25})_2$ is somewhat higher and is about I.6 radiation units.

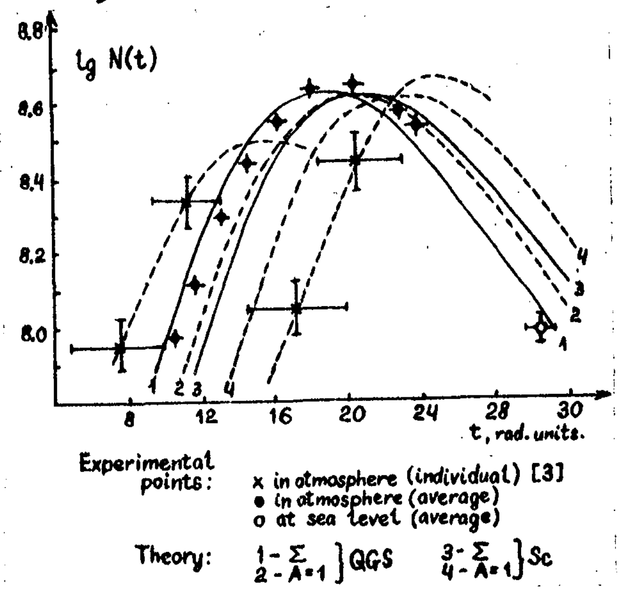


Fig. 2

Fig. 2 presents the mean cascade curve constructed using 26 individual cascade curves in EAS size units N(t). To construct the cascade curves in the absolute units N, the detectors of Cherenkov pulse shape were calibrated by comparing the pulses detected in them with the Cherenkov light flux densities $P_c$ [$cm^2 eV$] detected by the time-integral Cherenkov light detectors of the Yakutsk array /5/; $S = mP_C$, where S [mm,ns] is the Cherenkov pulse area measured initially on millimetre scale of amplitudes and on nanosecond sweep of oscillograph, m is calibration factor (which permits to express the amplitudes of pulses in units of flux density [$cm^{-2} ns^{-I} eV^{-I}$]). After that, using the theoretical functions /2,3/ one obtains the cascade curves N(t) for the number of shower electrons. The accuracy of the calibration factor m, hence of the EAS size N(t), is 25% and arises mainly from the accuracy of the absolute calibration of the integral detectors. The EAS size in the maximum of the mean cascade curve is $\overline{N_m}$ = (4.5 ±

± I.I).$10^8$. Fig. 2 also shows the point corresponding to the mean EAS size at sea level $\overline{N}_s = (0.95 \pm 0.06).10^8$ inferred from the data of the Yakutsk EAS array scintillators. The energy of individual cascade curves was also determined on the basis of the parameter $\rho_{600}$ /9/, The mean cascade curve energy is $\overline{E}_0 = (7.0 + 2.0).10^{17}$ eV. The correlation coefficient between $E_0$ and $N_m$ inferred from 26 experimental cascade curves is $\overline{K} = \overline{(E_0/N_m)} = (1.60 \pm 0.08).10^9$ for r.m.s. error 30% related mainly to the apparatus errors of determination of $E_0$ and $N_m$.

The comparison by the Pearson method between the experimental cascade curve and the theoretical curves calculated in terms of the scaling model (Sc) /6/ and the QGS model /8/ under various assumptions concerning the chemical composition of primary cosmic rays exhibits a better agreement of the experimental data with the QGS model for complex chemical composition (QGS, $\Sigma$) ($P(\chi^2) = 0.07$). Other versions of the theory are in a poorer agreement with the experimental data ($P(\chi^2) \leq 0.01$).

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