SOVIET PHYSICS JETP VOLUME 15, NUMBER 1 JULY, 1962

# *ON THE INTERPRETATION OF THE TWO-CENTER MODEL WITHIN THE FRAMEWORK OF THE HYDRODYNAMICAL THEORY*

A. A. EMEL'YANOV

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor June 20, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 171-172 (January, 1962)

For the description of "two-humped" showers within the framework of the hydrodynamical theory it is suggested that the dissipation of energy of a simple wave because of viscosity should be taken into account.

It has been shown earlier [1] that in some cases the kinematics of so called "two-humped" showers [2,3] can follow from the hydrodynamical theory. [4] In [1] the model of an ideal mesonic liquid was used to describe the disintegration of the excited system; in the present note the effect of a viscosity on the distribution of the particles that are produced is studied.

When the viscosity coefficient is small it can be shown [5] that the viscosity is not of much importance in the domain of the general solution and that its importance decreases with increasing energy. Nevertheless, for the region of the hydrodynamical motion near the front of the bursting meson cloud (where $\partial u_i/\partial x^i \gg 1$, $u_i$ being the four-velocity) inclusion of a small viscosity can decidedly alter the nature of the angular and energy distributions of the secondary particles. [6] The dissipation of energy in the vicinity of the front, and in particular in that of the simple wave, [6] leads to the production of a number of additional particles and to an increase of the degree of inelasticity of the elementary act. Since the particles produced during the bursting process are the fastest ones, inclusion of these particles can lead to the appearance of a "two-humped" shape of the angular distribution of all the shower particles.

Specific calculations have been made for two possible types of temperature dependence of the viscosity coefficient: 1) $\zeta = \text{const}$, and 2) $\zeta \sim T^3$ (T is the temperature of the medium).

According to estimates made earlier, [6] for $\zeta = \text{const}$ the number of particles $\Delta N$ produced on account of the viscosity in the region of the simple wave is given by

$$\Delta N = 0.4\,(\pi a^2 \zeta/\mu_\pi)\ln(E_0/\mu_\pi), \qquad (1)$$

where $\mu_\pi$ is the mass of the $\pi$ meson, $M = c = h = 1$, M is the mass of the nucleon, and $\pi a^2$ is the interaction cross section. The relation (1) is rigorously satisfied for $\Delta N/N \ll 1$, but it also gives the right value for $\Delta N/N \lesssim 1$.

Assuming for the meson cloud the model of an ideal gas, we have $\zeta = (\mu_\pi/\pi a^2)$. Consequently, $\Delta N = 0.4\ln(E_0/\mu_\pi)$. For $E_0 = 10^3$ BeV we have $\Delta N \approx 3.5$, i.e., on account of the energy dissipation only 7 particles are produced, whereas the original excited system had 12 particles. We shall use the quantity

$$D = (N_e - N_i)/n_s$$

as a measure of the deviation of the angular-distribution function from the normal Gaussian function (cf. [3]). Here $n_s$ is the total multiplicity of the process; $N_i$ is the number of particles included in the range $x = \pm 0.674\sigma$, where $x = \log\tan\theta_L$, $\theta_L$ is the angle of emergence of the particles in the laboratory reference system and $\sigma$ is the dispersion of the angular distribution; $N_e$ is the number of particles outside this range, $N_i + N_e = n_s$. For our special case $D = 0.37$; according to [3] this indicates a clearly "two-humped" angular distribution. In the framework of this example the quantity D will decrease slowly with increase of the energy $E_0$.

The assumption that $\zeta = \text{const}$ in the bursting bunch of mesons is of course not justified for the description of the entire bursting process, except perhaps for the state that immediately precedes the instant of disintegration of the system into individual particles. For the case in which $T \gg 1$ and the meson cloud shows large quantum-statistical fluctuations [7,8] we shall use the temperature dependence $\zeta \sim T^3$ for the viscosity coefficient. Such a viscosity can be obtained for a "gas" of quantum-statistical fluctuations with correlation length $\sim 1/T$. [8] In this case we have the following simple expression for $\Delta N$:

$$\Delta N = kT_0^2 \quad (2)$$

($T_0$ is the initial temperature), where the coefficient k is of the order of unity and must be determined from experiment.

Besides indicating a rapid increase of the "two-humped" behavior of the distribution with increase of the energy $E_0$, this model gives as the characteristic energy dependence of the multiplicity of the elementary act

$$n_s = k_0 E_0^{1/4} + k E_0^{1/2}, \quad (3)$$

i.e., depending on the value of the quantity k and on the energy range considered the multiplicity lies between the function $\sim E_0^{1/4}$ (which corresponds to the Fermi-Landau theory) and the function $\sim E_0^{1/2}$ of the Heisenberg theory.[9] Because of this the degree of "two-humpedness" of the angular distribution must increase with increase of $E_0$, and the rapidity of this increase depends on the multiplicity $n_s$.

The use of the model with $\xi \sim T^3$ is limited for large values of $E_0$, owing partly to the problem of the applicability of the hydrodynamical theory to the description of the initial state of the disintegration of the excited system.

Since for sufficiently high energies the longitudinal size $l \sim E_0^{-1/2}$ of the excited system at the initial instant will be smaller than the correlation length $\sim E_0^{-1/4}$, local equilibrium does not become established in the system.

The proposed interpretation of the cases of "two-humped" showers is entirely applicable both to cases of collisions of nucleons with nuclei and to nucleon-nucleon collisions. For the latter, however, we must resort to the additional assumption that there is incomplete transfer of the energy of the nucleons of the excited system (in order to justify the small value of the inelasticity coefficient which is observed experimentally).

In conclusion the writer expresses his deep gratitude to I. L. Rozental' for his interest in this work and for helpful comments.


1. A. A. Emel'yanov and I. L. Rozental', JETP **38**, 194 (1960), Soviet Phys. JETP **11**, 142 (1960).

2. Bartke, Ciok, Gierula, Holyński, Miesowicz, and Saniewska, Nuovo cimento **15**, 18 (1960).

3. Gierula, Miesowicz, and Zieliński, Acta Phys. Polon. **19**, 119 (1960).

4. S. Z. Belen'kii and L. D. Landau, Uspekhi Fiz. Nauk **56**, 309 (1955).

5. A. A. Emel'yanov, JETP **36**, 1550 (1959), Soviet Phys. JETP **9**, 1100 (1959).

6. A. A. Emel'yanov and D. S. Chernavskii, JETP **37**, 1053 (1959), Soviet Phys. JETP **10**, 753 (1960).

7. E. L. Feĭnberg, Uspekhi Fiz. Nauk **70**, 333 (1960), Soviet Phys. Uspekhi **3**, 147 (1960).

8. G. Iso and M. Namiki, Progr. Theoret. Phys. **18**, 591 (1957).

9. W. Heisenberg, Z. Physik **133**, 65 (1952).


Translated by W. H. Furry
26