ON THE THEORY OF NUCLEON COLLISIONS WITH HEAVY NUCLEI

A. A. EMEL'YANOV

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

Submitted to JETP editor June 21, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 1673-1674 (November, 1961)

Collisions between nucleons and heavy nuclei are considered within the framework of the hydrodynamic theory. It is shown that the reference system in which the secondary particle angular distribution possesses forward-backward symmetry is not the c system.

BELEN'KII and Milekhin[3,4] have considered the interaction of nucleons with nuclei using the hydrodynamic theory of Landau.[2] If $n < 3.7$ (where n is the number of nucleons in the tube), the problem is solved completely, but if $n > 3.7$, only the dependence of the multiplicity of the process on the dimensions of the nuclei has been obtained. In the present paper we present the results of investigating the symmetry properties of the distribution of shower particles with the help of the hydrodynamic theory for the case $n > 3.7$.[1]

If $n > 3.7$, a region of motion forms in the expanding meson cluster, called the second wave of rarefaction (s.w.r.), which is bounded by the vacuum on one side and on the other by the region of hydrodynamic motion which arises as a result of the reflection of the simple wave on the front of the shock wave[3] (called the first reflected wave). According to Milekhin,[5] the angular distribution of the secondary particles in the one-dimensional approximation[6] is given by the relation

$$\frac{dN}{d\eta} = -\frac{N_0}{3} e^{2y_k} \frac{\partial \Psi(\eta, y_k)}{\partial y_k}, \tag{1}$$

where $\Psi = \partial\chi/\partial y - \chi$, and $\chi(\eta, y)$ is the hydrodynamic potential determined by the equation of Khalatnikov:[7]

$$3\frac{\partial^2 \chi}{\partial \eta^2} - \frac{\partial^2 \chi}{\partial y^2} - 2\frac{\partial \chi}{\partial y} = 0. \tag{2}$$

Here $y = \ln(T/T_0)$, $\eta = \tanh^{-1} v$, T is the temperature of the medium, T_0 is the initial temperature, v is the velocity (velocity of light $c = 1$), N_0 is the total number of particles, $y_k = \ln(T_k/T_0)$, and T_k is the decay temperature.

For $|y_k| \gg 1$ the decay of the system is determined by the s.w.r. Solving Eq. (2) for the region of the s.w.r. by the method proposed by Milekhin,[4] we can determine the function $\partial\Psi/\partial y$. With an accuracy up to terms of order $1/|y|$ we have

$$\frac{\partial \Psi}{\partial y} = \frac{\sqrt{3}}{2} e^{-y}\Big[l\Big(\frac{\partial I_0(z)}{\partial y} - I_0(z)\Big) - t_1\frac{\partial I_0(z)}{\partial \eta} + \lambda\beta_k\left(I_0(z) + I_1(z)\right)\Big],$$

$$\lambda = 3 + \sqrt{3}, \quad \beta_k = (n - 2 - \sqrt{3})(2 + \sqrt{3})/(7 + 4\sqrt{3}),$$

$$z = \sqrt{y^2 - \eta^2/3}, \qquad t_1 = \sqrt{3}\lambda + \frac{(5\sqrt{3} + 9)\lambda\beta_k}{2(2 - \sqrt{3})},$$

$$l = \lambda + \frac{(5 + 3\sqrt{3})\lambda\beta_k}{2\sqrt{3}(2 - \sqrt{3})}. \tag{3}$$

Using relations (1) and (3), it is easy to show that the angular distribution of the secondary particles has forward-backward symmetry in the reference system moving with respect to the system of the center of gravity with a velocity V, where

$$V = \mathrm{th}\Big[\frac{4(n+1) + 3\sqrt{3}}{2(7 + 4\sqrt{3})} - \mathrm{Arth}\Big(\frac{n-1}{n+1}\Big)\Big]. \tag{4*}$$

For example, for a tube with $n = 6$ we have $V = 0.4$.

We note in this connection that the experimental determination of the energy of the system by the "half-angle" method leads to a lowering of the value of the energy by a factor $\exp(-2\tanh V)$ [for $n = 6$ we have $\exp(2\tanh V) = 2.2$]. The lowering of the energy leads again to a certain rise in the degree of anisotropy of the angular distribution of the shower particles.

For the system as a whole the violation of the symmetry will be due to particles in the simple wave (about one particle) and in the first reflected wave (about four particles). However, the contribution of these particles is small and decreases with increasing energy of the incoming nucleon. This last assertion may become invalid if account is taken of the viscosity, which leads to the formation of an additional number of particles in the region of the simple wave.[8]

*th = tanh, Arth = $\tanh^{-1}$.

[1] P. H. Malhotra and Y. Tsuzuki, Nuovo cimento **18**, 982 (1960). Bartke, Ciok, et al., Nuovo cimento **15**, 18 (1960).

[2] L. D. Landau, Izv. AN SSSR Ser. Fiz. **17**, 51 (1953).

[3] S. Z. Belen'kii and G. A. Milekhin, JETP **29**, 20 (1955), Soviet Phys. JETP **2**, 14 (1956).

[4] G. A. Milekhin, JETP **35**, 1185 (1958), Soviet Phys. JETP **8**, 829 (1959).

[5] G. A. Milekhin, JETP **35**, 978 (1958), Soviet Phys. JETP **8**, 682 (1959).

[6] I. L. Rozental', JETP **31**, 278 (1956), Soviet Phys. JETP **4**, 217 (1957).

[7] I. M. Khalatnikov, JETP **26**, 529 (1954).

[8] A. A. Emel'yanov and D. S. Chernavskii, JETP **37**, 1058 (1959), Soviet Phys. JETP **10**, 753 (1960).

Translated by R. Lipperheide
278