The NDR appears in relatively weak electric field when $T_e I \sim 0.1 - 0.2$.

Bearing in mind the possibility of experimentally separating these mechanisms, we note that the second mechanism leads to NDR in a strong electric field ($T_e(E) \sim I$), when almost all the impurities are ionized, while the first and third mechanisms appear in a weak field. The third "works" when N_d is close to the density corresponding to the Mott transition.

[1] E. H. Putley, Proc. Int. Conf. Phys. Semicond. Paris, 1964, p. 443.
[2] A. L. McWhorter and R. H. Redicher, Proc. Int. Conf. Phys. Semicond. Prague, 1960, p. 134.
[3] T. M. Gasymov and L. E. Gurevich, Fiz. Tverd. Tela 9, 106 (1967) and 11, 2946 (1969) [Sov. Phys.-Solid State 9, 78 (1967) and 11, No. 4 (1970)].
[4] A. M. Zlobin and P. S. Zyryanov, Fiz. Met. Metalloved. 26, 961 (1968).
[5] V. L. Bonch-Bruevich, FTT (Solid State Physics), Collection No. 2, 177 (1959). A. A. Rogachev and M. I. Sablina, Fiz. Tverd. Tela 8, 187 (1966) [Sov. Phys.-Solid State 8, 146 (1966)].
[6] E. N. Fenton and R. R. Haering, Phys. Rev. 159, 593 (1967).

PERIPHERAL PARTICLE GENERATION AT HIGH ENERGY

V. A. Kolkunov, E. S. Nikolaevskii, and K. A. Ter-Martirosyan

Submitted 26 January 1970
ZhETF Pis. Red. 11, No. 5, 260 - 264 (5 March 1970)

It will be shown below that the spectra of π^-, K^-, and $\bar{p}$, obtained [1] by the combined group of CERN and the Institute of High Energy Physics (IHEP) by irradiating Al^{27} nuclei with 70-GeV protons, are well described by the simple model of peripheral production corresponding to the diagram of Fig. 1a. The rapid decrease of the spectra [1] with increasing laboratory energy of the particles is a consequence of the decrease of the vertex G of the transformation of the proton into the system of final particles (π^-, Δ^{++}, or K^- (K^+p) or $\bar{p}(pp)$) - in the region of not very large values of its mass $\sqrt{s_1}$, of the order of the resonant values. Let us consider first the reaction $pZ \to \pi^- \Delta^{++} Z'$, where Z is the Al nucleus (or one its nucleons). The diagram of Fig. 1 corresponds to the amplitude

$$T = \eta_\alpha g_Z(t) G(s_1, u_1; t) s^{\alpha(t)}, \qquad (1)$$

where $\alpha(t) = 1 + \alpha'(0)t$ is the trajectory of the Pomeranchuk pole, $\eta_\alpha = i - \cot\pi\alpha/2 \approx i \exp(-(i\pi/2)\alpha'(0)t)$, the invariants $s_1 t$ and s_1, u_1 are indicated in Fig. 1, and the vertex G is represented in the form

$$G = \tilde{g}(t) \frac{e^{-\gamma s_1} + \lambda s_1^{1+\beta(u_1)}}{s_1^{\alpha(t)}(s_1 - m_0^2 + i m_0 \Gamma_0)}, \qquad (2)$$

in which it exhibits at small $s_1 \sim m_0^2$ a resonant behavior corresponding to formation [2] and decay[1)] of a resonance (Fig. 1b) with mass m_0 and width Γ_0 into π^- and Δ^{++}, and $s_1 >> m_0^2$ it has a Regge behavior $G \sim s_1^{\beta(u_1) - \alpha(t)}$, which yields in (1) a multireggeon response $T \sim s_1^{\beta(u_1)} s_2^{\alpha(t)}$ for $s_1 >> m_0^2$ [3] we have $s \approx s_1 s_2 m_\Delta^{-2}$, see Fig. 1c). By γ and λ we denote in (2) certain parameters, and the resonant state is chosen to be M(1410) with I = 1/2, the

[1)] No account is taken in the first term of (2) of the dependence of this decay on the direction $\vec{n}_{12}$ in the rest system of the resonance (i.e., on u_1, see Fig. 1). In addition, it is assumed that the dependence on t in G is separated in the form of a factor $\tilde{g}(t) \sim \exp(R_\rho^2 t/2)$.

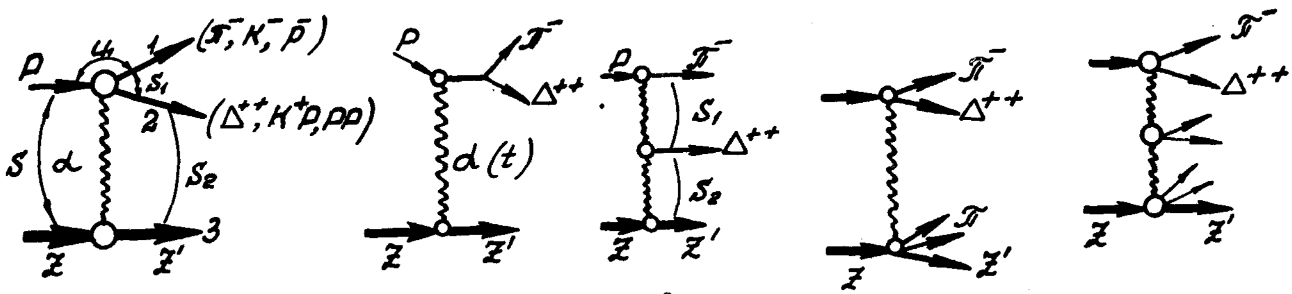

Fig.1

formation of which has the largest probability; for this state, $m_0 = 1.4$ and $\Gamma_0 = 0.2$ (all the quantities are expressed in GeV or in GeV^2). Other states, for example M(1680), which are also produced, are not takeninto account. The vertex $\tilde{g}(t)$ in (2) depends also on the mass m_2 Δ^{++}; we assume that

$$g_Z(t)\tilde{g}(t) = (4\pi)^2\tilde{\gamma}e^{R^2t}\phi(m_2) \qquad (3)$$

and average the cross section over the form of the spectrum, choosing

$$\Phi = \Phi_1 = \frac{m_\Delta \Gamma_\Delta}{m_\Sigma^2 - m_\Delta^2 + i m_\Delta \Gamma_\Delta}$$

or specifying $\Phi = \Phi_2 \exp[a(m_\Sigma^2 - m_2^2)]$, where $m_\Sigma = m_\pi + m_p$, and a is the certain parameter.

Calculating the phase volume

$$d\tau_3 = (2\pi)^4\delta^{(4)}(P - \sum_{i=1}^{3} p_i)\Pi d^3p_i(2\pi)^{-3}(2\epsilon_i)^{-1} = (4\pi)^{-4}p_1 dE_1 d\cos\theta_1 2p_{23} m_b^{-1} dz_o d\phi_o .$$

we obtain the cross section $d\sigma = |T|^2(4\sqrt{s}\,p)^{-1}d\tau_3$ in the form

$$\frac{d^2\sigma}{dE_1 d\cos\theta_1} = m_z E_o p_1 \frac{2p_{23}}{m_b}\int_{-1}^{+1} dz_o \int_{o}^{2\pi} d\phi_o \left|\frac{T}{(4\pi)^2 s}\right|^2, \qquad (4)$$

where $p_1 = (E_1^2 - m_1^2)^{1/2}$ and θ_1 are the laboratory energy and the emission angle of π^-, E_0 is the laboratory energy of the incoming proton ($p\sqrt{s} \simeq m_z E_0$, m_z is the mass of the target nucleus), and p_{23} and m_b are the momentum and total energy of the two remaining particles, the recoil nucleus and Δ^{++}, in their c.m.s., with

$$2p_{23}m_b = \left\{\left[1 - \left(\frac{m_2 + m_3}{m_b}\right)^2\right]\left[1 - \left(\frac{m_2 - m_3}{m_b}\right)^2\right]\right\}^{1/2},$$

where m_2 and m_3 are the masses of these particles and $m_b^2 = (P - p_1)^2 = s(1 - \epsilon)$, $s \simeq 2m_z E_0$, and

$$\epsilon \simeq \frac{E_1}{E_o}\left(1 + \frac{E_o}{2m_z}\theta_1^2\right) \simeq \frac{E_1}{E_o}\left(1 + \frac{s\,\theta_1^2}{4m_z^2}\right). \qquad (5)$$

The integration in (4) is over all the directions $\vec{n}_{23} = (\theta_0, \theta_0)$ of the momentum P_{23} in the c.m.s. of the recoil nucleus and Δ^{++}. The invariants s_1 and $t(z_0)$ (7) depend on $z_0 = \cos\theta_0$, and the contribution to (4) is made by the region of small θ_0, i.e., $z_0 \simeq 1$ $(s_1 = m_1^2 + m_2^2 + s\varepsilon\sqrt{1-\varepsilon}\,(1 - z_0)/2)$.

$|T|^2$ does not depend on θ_0 at very small lab angles θ_1 (at $E_0\theta_1 < m_0$), i.e.,

$$\int_0^{2\pi} d\phi_0 \, |T|^2 = 2\pi |T|^2 .$$

We therefore obtain here from (1) - (4) approximately, introducing in place of z_0 the variable s_1:

$$\frac{d^2\sigma}{dE_1 d\cos\theta_1} = 2\pi\tilde{\gamma}^2 E_1 \int_{s_1^0}^{\infty} e^{2\lambda t} |f|^2 ds_1 , \qquad (6)$$

where f is the factor of $\tilde{g}(t)$ in (2) when $u_1 = 0$, $\lambda = R^2 + \alpha'(0)\ln E_0$, and $s_1^0 = m_1^2/\varepsilon + m_2^2/(1-\varepsilon)$ is the minimum value of s_1 in (4), corresponding to $\cos\theta_1 = 1$ and

$$-t = (E_0\theta_1)^2 + \sqrt{1-\varepsilon}(s_1 - s_1^0) + \Delta t , \qquad (7)$$

where $\Delta t = E_0\theta_1^2\, x(s_1 - s_1^0)^{1/2} \cos\phi_0$ $(x = 2\sqrt{\varepsilon(1-\varepsilon)}$ is the term not accounted for in (2), which is small in the region $E_0\,\theta_1 \sim m_p)$[2]. It is seen from (5) - (7) that $d^2\sigma/dE_1 d\cos\theta_1$ decreases rapidly with increasing $y = E_0\theta_1 m_p^{-1}$ at a given $\varepsilon_0 = E_1/E_0$, for this increases $(-t)$. Formulas (6) - (8) contain a unique "self-similarity": the quantity $d^2\sigma/dE_1 d\cos\theta_1$ in these formulas depends on the variables $y = E_0\theta_1 m_p^{-1}$ and $\varepsilon_0 = E_1/E_0$ in place of θ_1, E, and E_0. This was noted in [4].

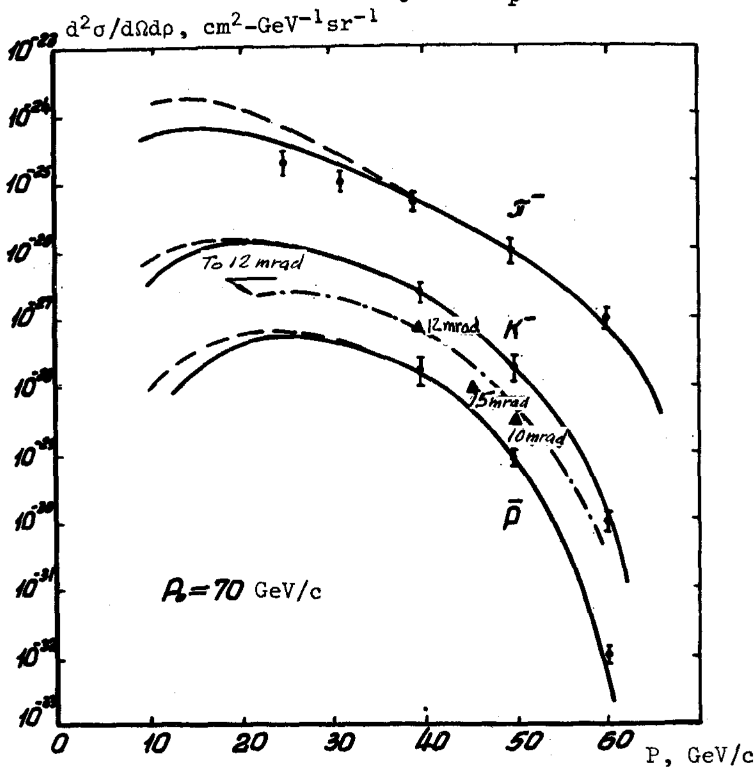

Fig. 2

These formulas can be obtained in a simple model, assuming that when the proton moves past Al^{27} (or past the nucleon) it is excited and is transformed into a certain state with mass $\sqrt{s_1}$, which moves in the laboratory system with a velocity $\beta_0 \simeq p_0/E_0 \simeq 1$, has an energy E, and decays into π^- and Δ^{++} in a certain direction $\vec{n}_1(z_1, \phi_1)$ in their c.m.s. The Lorentz tranformation

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[2] Allowance for this term adds the following factor in (6):

$$\int_0^{2\pi} d\phi_0 \exp(2\lambda\Delta t) = I_0(2\lambda i E_0\theta_1 x\sqrt{s_1 - s_1^0}) .$$

from this system to the laboratory system

$$E = (\omega_1 + z_1 k_1) E_0 / \sqrt{s_1}, \quad \omega_1 = \frac{s_1 + m_\pi^2 - m_\Delta^2}{2\sqrt{s_1}}, \qquad k_1 = \sqrt{\omega_1^2 + m_\pi^2}$$

leads to the aforementioned "self-similarity"

$$\epsilon = \frac{\omega_1}{\sqrt{s_1}} + \frac{k_1 z_1}{\sqrt{s_1}}$$

and to the distribution (6).

The π^- spectra obtained with the aid of the "exact" formulas (1) - (4) (for $\theta_1 = 0$) and with the aid of the approximate formulas (5) - (7) are shown by the solid and dashed lines in Fig. 2, respectively, where $\gamma = 0$ and $\lambda = 0.01$, following averaging of (4) and (6) over m_2^2 with a weight function $\Phi = \Phi_2(m_2)$ with a = 1. They are very close to each other and agree well with the experimental data [1].

The spectra of K^{-1} and $\bar{p}$ are similarly plotted on Fig. 2. In both cases, good agreement with experiment is obtained at $\gamma = 0.5 - 0.2$ with $\lambda = 0$ and with a large coefficient a in $\Phi_2(m_2)$. As seen from Fig. 2, the spectra shift regularly with increasing θ_1.

Besides Fig. 1a, contributions are made by the diagrams of Fig. 1d and Fig. 1e with several "jets" of particles. Allowance for these contributions leads to a steeper decrease of the spectra (since these diagrams enrich their parts), and possibly does not disturb the agreement with experiment, producing only a small change in the parameters, viz., an increse of λ in the case of π and a decrease of γ in the cases of K^- and $\bar{p}$.

Vertices of type (2) play an important role in high-energy physics - their variation and magnitudes determine, particularly, the contribution [3] of branch cuts to the total interaction cross sections.

The authors are grateful to L. B. Okun' and V. V. Anisovich for a number of remarks, and to Yu. D. Prokoshkin for a discussion and for acquainting them with the data of the experiment [1].

[1] Yu. B. Bushnin, S. P. Donskov, and A. F. Dunaitsev, et al., Phys. Lett. 29B, 48 (1969).
[2] S. Mandelstam, Nuovo Cim. 30, 1127, 1148 (1963).
[3] K. A. Ter-Martirosyan, Nucl. Phys. 68, 591 (1964).
[4] A. Liland and H. Pilkuhn, Phys. Lett. 29B, 604 (1969).

GYROTHERMAL EFFECT IN CRYSTALS AT LOW TEMPERATURES

B. I. Shklovskii and A. L. Efros
A. F. Ioffe Physicotechnical Institute, USSR Academy of Sciences
Submitted 26 January 1970
ZhETF Pis. Red. 11, No. 5, 265 - 266 (5 March 1970)

The purpose of this paper is to call attention to a new effect, namely that a crystal can rotate under the influence of a temperature gradient. For example, if a potential difference is produced on the ends of a long rod with thermally insulated lateral surface, then the rod will acquire an angular momentum M directed along its axis and proportional to the resultant heat flux q