injection of heavy particles. The condition $\alpha_{\text{plasma}} > \alpha_k \sim Z^2/m$ shows that the quarks are non-injectively accelerated in such a medium only if the same is ensured (with a margin by a factor m_q/m_N) for the protons. However, α_{plasma} can be large: when $n \sim 10^{-2}$ we get $\alpha_{\text{plasma}} \sim Z^2(m_N/m)^2 \times 10^{-9}w$ sec^{-1}, which can readily yield $\alpha_{\text{plasma}} t_0 \gg 1$. Therefore if the excess of heavy nuclei is connected not with the predominant injection for $Z^2/A > 1$ but with the increased abundance of heavy nuclei in c.r. sources, and if the acceleration is ensured by plasma waves, then the quarks will also be effectively accelerated by this mechanism, so that ξ may reach $\sim 10^{-11}$.

Let us summarize. We can expect the primary flux of cosmic rays to contain quarks, especially in the low energy region, $E_q/m_q c^2 \lesssim 10$. The ratio ξ of their flux to the proton flux can be smaller than the average relative concentration of cold quarks by several orders of magnitude, $\xi \sim 10^{-15}\, m_N/m_q$ (see items 2 and 3), but can also reach (or even exceed by one order of magnitude) $\xi \sim Q \sim 10^{-11}$, for example if the c.r. acceleration is by the statistical non-injective mechanism (items 4 and 5).

Experiment [5,6] has yielded so far $\xi < 10^{-8}$. The quarks can hardly be detected if $I_q < 10^{-11} - 10^{-12}$ cm^{-2}sec^{-1}. It would be important to make further progress in the region of low intensities, paying particular attention to quarks having relatively low energies.

In conclusion, I thank V. L. Ginzburg, Ya. B. Zel'dovich, S. B. Pikel'ner, and V. N. Tsytovich for interesting discussions.

[1] V. M. Maksimenko, I. N. Sisakyan, E. L. Feinberg, and D. S. Chernavskii, JETP Letters 3, 340 (1966), transl. p. 219.

[2] Ya. B. Zel'dovich, L. B. Okun', and S. B. Pikel'ner, UFN 87, 113 (1965), Soviet Phys. Uspekhi 8, 702 (1966).

[3] V. L. Ginzburg and S. I. Syrovat-skii, Proiskhozhdenie kosmicheskikh luchei (Origin of Cosmic Rays), AN SSSR, 1962.

[4] V. N. Tsytovich, DAN SSSR 142, 319 (1962), Soviet Phys. Doklady 7, 43 (1962); Astron. zh. 42, 33 (1965), Soviet Astronomy AJ 9, 24 (1965).

[5] A. W. Sunyar, A. Z. Schwarzschild, and P. I. Connors, Phys. Rev. 136B, 1157 (1964).

[6] T. Bowen et al., Phys. Rev. Lett. 13, 728 (1964); D. A. De Lise and T. Bowen, Phys. Rev. 140B, 458 (1965).

ALLOWANCE FOR THE INFLUENCE OF ππ SCATTERING ANNIHILATION CHANNELS IN THE REACTION N(π,2π)N

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In calculating the pion production reaction in πN collisions in accord with the Chew-Low diagram, it is customary to take into account in the ππ scattering node only the direct channel [1], corresponding to the "coalescence" of the pions into a ρ meson and decay of the latter. This leads to the notion that the concrete cross section of $\pi^+\pi^-$ scattering must also reach the unitary limit at the ρ-meson resonance point. However, besides the direct channel there are also annihilation channels, allowance for which, as will be shown presently, noticeably alters the expected characteristics of ππ scattering.

To take the annihilation channels into account, we can use the model of ππ interaction via ρ-meson exchange [2,3]. The method of the paper by Afonin and Granovskii [3] makes it possible to calculate the concrete cross sections for ππ scattering, and we chose for concreteness in this paper, from the very outset, the reaction $\pi^+\pi^- \to \pi^+\pi^-$. The amplitude of such a process is expressed in terms of the amplitudes with total isospin $\vec{T} = 0, 1, 2$ as follows:

$$M = \frac{1}{6}(2M^0 - 3M^1 + M^2). \tag{1}$$

Retaining only the $\vec{S}$ and $\vec{P}$ waves in the partial-wave expansions of isotopic amplitudes, we can write

$$\sigma(\pi^+\pi^- \to \pi^+\pi^-) = (\pi/9\vec{q}^2)(\vec{A} + \vec{C}/3), \tag{2}$$

where

$$\vec{A} = 4\sin^2\delta_0^0 + \sin^2\delta_0^2 - 4\cos(\delta_0^2 - \delta_0^0)\sin\delta_0^0\sin\delta_0^2,$$

$$\vec{C} = 81\sin^2\delta_1^1,$$

δ is the phase, the upper and lower symbols designate the total isospin and the orbital angular momentum, and $\vec{q}$ is the c.m.s. momentum. Were we to take only the direct channel into account, we would have in lieu of the cross section (2)

$$\sigma = (4\pi/\vec{q}^2)(\vec{C}/27) \tag{3}$$

which is equal to the unitary limit (117 mb) for the $\vec{P}$ wave at the point $W^2 = \rho^2 = 30\mu^2$ (W is the total c.m.s. energy). We see (Fig. 1) that when the annihilation channels are taken into account the cross section $\sigma(\pi^+\pi^- \to \pi^+\pi^-)$ does not reach this unitary limit. If we use for the coupling constant the value [3] $(\gamma^2/4\pi)_{\rho\pi\pi} = 1.5$, which corresponds to a resonance width $\Gamma = 150$ MeV, then the cross section of the reaction $\pi^+\pi^- \to \pi^+\pi^-$ at the resonance point turns out to be $\sigma = 32$ mb, and the width is $\Gamma = 180$ mb, which does not contradict the available experimental data [4] obtained by the Chew-Low method [5].

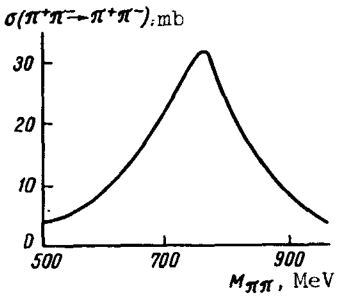

Fig. 1. Cross section of the reaction $\pi^+\pi^- \to \pi^+\pi^-$.

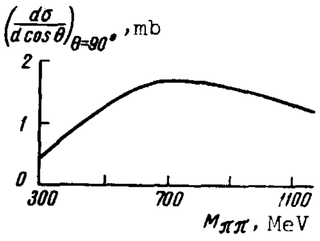

Fig. 2. Differential cross section $(d\sigma/d\cos\theta)_{\theta=90°}$ for the reaction $\pi^+\pi^- \to \pi^+\pi^-$.

Favoring the inclusion of the annihilation channels of $\pi\pi$ scattering is also the presence of an $\vec{S}$ wave in the ρ-meson resonance region. This causes the differential cross section $d\sigma/d\cos\theta$ at 90° not to be equal to zero (Fig. 2), as would be the case if only the direct channel were taken into account, but to have the form of a broad peak with a maximum of the order of 2 mb, located very slightly below the ρ-meson resonance, in qualitative agreement with experiment [6].

I am grateful to P. A. Usik for a useful discussion.

[1] F. Selleri, Phys. Lett. 3, 76 (1962).

[2] L. D. Solov'ev and Ch'en Ts'ung-mo, JETP 42, 526 (1962), Soviet Phys. JETP 15, 369 (1962).

[3] A. A. Afonin and Ya. I. Granovskii, JETP 44, 1896 (1963), Soviet Phys. JETP 17, 1276 (1964).

[4] Saclay-Orsay-Bari-Bologna Collaboration, Nuovo Cimento 29, 515 (1963) and 35, 713 (1965).

[5] G. F. Chew and F. E. Low, Phys. Rev. 113, 1640 (1959).

[6] A. R. Clark, J. H. Christenson, J. W. Cronin, and R. Turlay, ibid. 139B, 1556 (1965).

ERRATA

Article by I. M. Barkalov et al., v. 3, No. 8

On p. 201 lines 26-27 instead of $V = 0.74$ with $V_0 = 0.62$ cm^3/g read $V = 0.74V_0 = 0.62$ cm^3/g.

Article by Yu. V. Gulyaev and E. M. Epshtein, v. 3, No. 10.

In formula (4) on p. 269 read $\Gamma(5/2)$ instead of $\Gamma(s/2)$.