$10^{12} - 10^{13}$ cm^{-3}, and this led to an increase of the slowing down in the section to a value 0.3 - 0.5 in the frequency range under consideration.

During the course of the pulse, the beam energy ranged from 0.3 to 1.0 MeV. The width of the resonance between the beam and the excited waves with frequency ω and wave number k_z is

$$\left|\frac{\omega}{k} - v_0\right| \sim \left(\frac{\omega_b}{\omega_0}\right)^{2/3} \frac{v_0^{4/3}}{v_g^{1/3}} \sim v_0 \quad (3)$$

where v_0 is the beam velocity, ω_b is the Langmuir frequency of the beam, v_g is the group velocity of the wave, and ω_0 is the resonant frequency of the section. Under the conditions of the experiment, the beam is at resonance with the excited waves during the entire pulse.

The length ℓ over which the oscillations build up is of the order of $\ell \sim 10 v_0^{2/3} v_g^{1/3} / \omega_b^{2/3} \omega_0^{1/3} \simeq 20 - 30$ cm, i.e., much less than the length of the section.

Thus, self-modulation of the beam produces a noticeable effect. The self-modulation is accompanied by generation of intense microwave oscillations at the resonant frequency ω_0. The microwave power was measured by two methods, with a calibrated detector and with a calorimeter matched to the waveguide channel (SWR = 1.35). The power reached 10^7 W. The generation of radiation was observed in the entire range of waveguide frequencies, with a maximum at 2600 MHz, and its duration was 3×10^{-8} sec.

[1] O.G. Zagorodnov, I.N. Magda, N.P. Gadetskii, V.I. Belyaev, and Yu.V. Tkach, Prib. Tekh. Inst. No. 6, 89 (1971).
[2] M.L. Andrews, H. Davitan, H.H. Fleishman, and J.A. Nation, Phys. Fluids 14, 11 (1971).
[3] B.J. Eastlung, Nucl. Fusion 11, 15 (1971).
[4] A.A. Vedenov and R.Z. Sagdeev in: Fizika plazmy i problema upravlyaemykh termoyadernykh reaktsii (Plasma Physics and the Problem of Controlled Thermonuclear Reactions), AN SSSR 3, 278 (1958).
[5] A.A. Ivanov and L.I. Rudakov, Zh. Eksp. Teor. Fiz. 58, 1332 (1970) [Sov. Phys.-JETP 31, 715 (1970)].
[6] Ya.B. Fainberg, V.D. Shapiro, and V.I. Shevchenko, ibid. 57, 966 (1969) [30, 528 (1970)].

COHERENT GENERATION OF THE $2\pi^-\pi^+$ SYSTEM ON NUCLEI

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We have obtained new data on the coherent generation of a triad of pions ($\pi^+ 2\pi^-$) on light nuclei (C, F, Cl) by a π^- meson having a "momentum" $\sim$3.9 GeV/c. Some experimental details can be found in [1].

An increase of the statistics has enabled us to study a group of reactions (202 events) with $t' = |t - t_{min}| < 0.03$ (GeV/c)^2, in which the fraction of the coherent events, according to the most rigorous estimates, is not lower than 40%. The general characteristics of this group can be seen in Fig. 1. The presented mass distributions agree qualitatively with the corresponding distributions observed in similar experiments at higher energies.

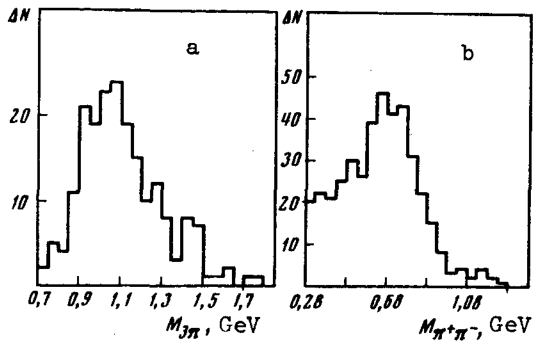

Fig. 1

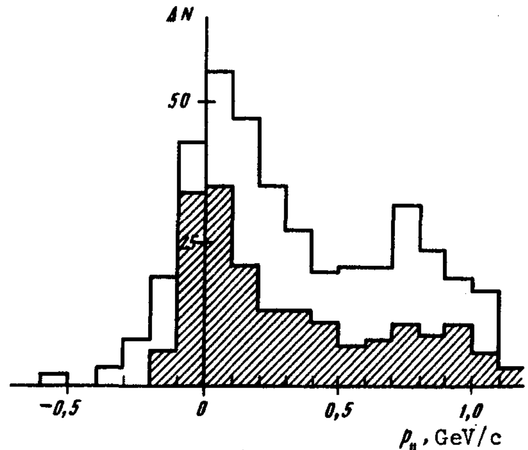

Fig. 2

Fig. 1. Mass distributions of the systems $(\pi^+ 2\pi^-)$ (a) and $(\pi^+\pi^-)$ (b) for events with $t' \leq 0.03\ (\mathrm{GeV}/c)^2$ (the reaction $\pi^- + A \to A + \pi^+ + 2\pi^-$).

Fig. 2. Distributions of the longitudinal momenta of the π^+ and π^- mesons for events with $t' \leq 0.03\ (\mathrm{GeV}/c)^2$, in the mass center of the "incident particle + nucleon" system. Light part - π^- mesons (404 combinations), shaded part - π^+ mesons (202 events).

In our case, the yield of the coherent reaction depends on the mass of the produced triad. Thus, at values $M_3 \gtrsim 1.2$ GeV there is no coherent process. This result confirms estimates of the fundamental papers [2]. The masses of the systems $(\pi^+ 2\pi^-)$ and $(\pi^+\pi^-)$ are also mutually dependent. One can see a ρ_0 meson in the interval $0.95\ \mathrm{GeV} < M_3 < 1.2$ GeV, but not in the region $M_3 \leq 0.95$ GeV. Since there is a distinct diffraction peak for the reactions with $\overline{M}_3 < 0.95$ GeV, this fact can be regarded as a consequence of the coherent generation of a triad of uncorrelated pions.

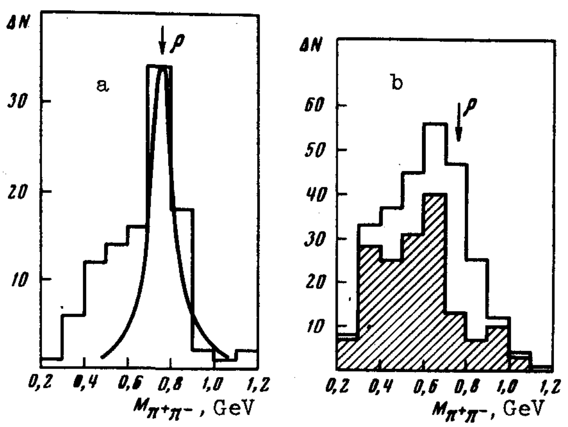

Fig. 3. Mass spectrum of the $(\pi^+\pi^-)$ system for events with a π^+ meson having $p_{\parallel} > 0.5$ GeV/c (a), and the same for events with a fast π^- meson (b). The difference between the distributions (b) and (a) is shown shaded. The smooth curve is the Breit-Wigner distribution corresponding to the ρ meson.

The momentum distribution of the secondary particles turned out to be a sensitive criterion.

Figure 2 shows the distributions of the longitudinal component of the momentum in "incident particle + nucleon" system. For pions of both signs, there are groups of "soft" and "fast" particles, with a distinct boundary at $p_{\parallel} \simeq 0.5$ GeV/c. In 95% of the cases there is only one fast particle, and the two others have $p_{\parallel} < 0.5$ GeV/c. This allows us to conclude that the total number of fast particles corresponds to the number of reactions.

The fast π^+ mesons are connected with peripheral production of a ρ^0 meson. This is confirmed by Fig. 3a. The ρ^0-meson peak is clearly pronounced. It is shown with the aid of the angular distributions that the generated ρ meson is aligned in a direction perpendicular to the motion of the primary pion. This should lead to the appearance of fast π^- mesons in an amount equal to the number of fast π^+ mesons. It is seen from Fig. 2 that this reason alone does not suffice to explain the observed number of π^- mesons with $p_\parallel > 0.5$ GeV/c. This conclusion is additionally illustrated by Fig. 3b, where the ρ meson was not separated against the background of the accompanying spectra in the mass distribution of the $(\pi^+\pi^-)$ system for events with fast π^- mesons. The difference between Figs. 3b and 3a is concentrated, in the main, to the left of $M_{\pi^+\pi^-} \sim 0.7$ GeV, i.e., it is not connected at all with the ρ meson.

Thus, Figs. 2 and 3 offer evidence of the existence of a reaction that leads to formation of a fast preferred particle that coincides with the primary one, i.e., to the production of a "leader."

The existence of a "leader" is confirmed also by the mass distribution of the $N\pi^-$ system. The observed singularities of this spectrum are due entirely to the influence of the group of fast particles with $p_\parallel > 0.5$ GeV/c.

The role of the isobar N*(1238) in the formation of the $N\pi^-$ mass spectrum is negligible, a fact that may indicate a larger fraction of coherent reaction in the sample under consideration.

We have analyzed qualitatively the angular distributions of the secondary pions. The analysis has revealed generation of $(\pi^+2\pi^-)$ triads in the states $I^P = 0^-$ and 1^+, as expected for the coherent process. The distribution with respect to the π^--meson emission angle relative to the beam in the c.m.s. of the $(\pi^+2\pi^-)$ triad agrees with the decay scheme $I^P = 0^-, 1^+ \rightarrow 0^- + 0^- + 0^-$.

The total cross section of the coherent process, determined by a standard extrapolation of the $d\sigma/dt'$ distribution into the region of small transfers, referred to an average nucleus (A = 22.5) turned out to be $\sigma_c = (630 \pm 290)$ μb/nucleus. This quantity was used to estimate the cross section for the interaction of the pion triad with the nucleon inside the nucleus, $\sigma_{3\pi N}$, in accordance with the procedure of [3]. The calculation yields $\sigma_{3\pi N} > 2\sigma_{\pi N}$. The estimate shows that the contribution of the bound states of three pions to the coherent process is small.

Thus, the entire aggregate of the experimental data indicates that we have observed coherent generation of a triad of uncorrelated pions.

It is likewise impossible to exclude a considerable contribution of the coherent process that leads to the formation of the $\rho^0\pi^-$ pair.

As to the first statement, the facts listed above can be explained by representing the process as a stripping of virtual pions from the primary particle (the "leader") by the field of the nucleus. As is well known, such a pion "bremsstrahlung" was predicted, in essence, already by Pomeranchuk and his coworkers, and also in recent papers by Benecke et al. and by Feynman, in connection with cosmic-ray physics.

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[1] V.G. Kirillov-Ugryumov, V.I. Levina, A.K. Ponosov, V.P. Protasov, and F.M. Sergeev, ZhETF Pis. Red. 14, 168 (1971) [JETP Lett. 14, 110 (1971)].

[2] I.Ya. Pomeranchuk and E.L. Feinberg, Dokl. Akad. Nauk SSSR 93, 439 (1953); M.E. Good and W.D. Walker, Phys. Rev. 120, 1857 (1960).
[3] T.F. Hoang, Nuovo Cim. 69, 327 (1970).
[4] I. Benecke, T.T. Chou, C.N. Yang, and C. Yen, Phys. Rev. 188, 2159 (1969); R. Feynman, Phys. Rev. Lett. 23, 1415 (1969).

ACTIVATIONLESS HOPPING CONDUCTIVITY IN COMPENSATED GERMANIUM

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At low temperatures, the conductivity of doped semiconductors is produced, as is well known, by a hopping mechanism [1, 2], wherein the charge is transported via tunnel transitions (hopping) of the electrons from occupied to free impurity centers, the presence of which is ensured by the compensation. The presence of activation energy is connected with the scatter of the impurity levels in the random fields of the charged donors and acceptors, and as the electron moves it is quite likely to absorb or emit a phonon, on the average with equal frequency. The need for absorbing a phonon leads to an exponential dependence of the conductivity on the temperature. However, in a sufficiently strong field, the hopping conductivity can become in principle activationless [3]. To this end, it is necessary that the potential-energy drop over the length R of the hop, in an electric field eER, be comparable with the energy spread Δ of the impurity centers. In this case the electron hops will be accompanied only by the emission of phonons, and the conductivity ceases to depend on the temperature. Simple estimates show, however, that in the region of the classical hopping conductivity over shallow impurities it is impossible to observe this effect, since impact ionization of the impurity centers occurs in much weaker fields. More favorable possibilities are uncovered by further lowering of the temperature, when the conductivity is due to the hopping of the electrons not over the nearest impurities, but over states located in a narrow energy band near the Fermi level. In this region, the conductivity σ decrease with temperature in accordance with the formula [4]

$$\sigma = \sigma_0 \exp\left(-\frac{T_0}{T}\right)^{1/4}, \quad T_0 \sim \frac{1}{g(\mu)a^3}, \tag{1}$$

where g(μ) is the density of states at the Fermi level and a is the Bohr radius. The value of the critical field needed to observe activationless hopping conductivity is in this case greatly reduced, for Δ decreases and R increases with decreasing temperature. In strongly doped and strongly compensated germanium, a conductivity of the "$T^{-1/4}$" type (1) was observed in the experimentally convenient region of nitrogen - helium temperatures [5], and in addition the strong compensation leads to a lowering of the Fermi level into the forbidden band and to an increase of the impact-ionization field. These circumstances governed the choice of the object of the investigation. The experiments were performed on samples of germanium strongly doped with phosphorus ($N_0 \approx 10^{19}$ cm^{-3}) and simultaneously strongly compensated with gallium. The degree of compensation was of the order of 80%.[1)]

Owing to the strong compensation, the samples were not homogeneous and their Hall coefficient was not measured. The current-voltage characteristics of the samples were nonlinear and accompanied by breakdown under stationary

[1)] We are sincerely grateful to R.L. Korchazhkina for preparing the strongly-compensated germanium samples.