the energy losses of an individual high-energy particle in a dense substance.

Certain examples of recorded events are shown in Fig. 2. In the future we plan to place a cloud chamber over the energy detector to permit study of an elementary interaction event between nuclear-active particles of known energy and nuclei of specified atomic numbers.

A detailed description of the experimental data obtained with the above instrument will be published.

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COLLECTIVE MOTIONS IN A SYSTEM OF QUASI-PARTICLES

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IN the self-consistent field approximation the consideration of a strong interaction between particles leads to a dependence of the energy of a separate particle (which is considered as a quasi particle) on the state of motion of the other particles in the system. Even in the case of a spatially uniform distribution of the particles in the system, a consideration of the interaction leads to a complicated dependence of the particle energy on its momentum.*

The Hamiltonian function of a quasi particle in the case of a non-uniform distribution in space can be taken in the form

$$\varepsilon_j(\mathbf{p}) + \int G(|\mathbf{r}-\mathbf{r}'|) \sum_i |\psi_i(\mathbf{r}')|^2 d\mathbf{r}', \qquad (1)$$

where the first term takes into account correlations at small distances apart and the kinetic energy, while the second term refers to long-range interactions (Hartree field). The equation of motion for ψ_j is of the form

$$\varepsilon_j(\hat{\mathbf{p}})\varphi_j + \int G(|\mathbf{r}-\mathbf{r}'|) \sum_i |\psi_i(\mathbf{r}')|^2 d\mathbf{r}' \psi_j = \varepsilon_j\psi_j. \qquad (2)$$

We shall restrict our considerations to those states of the system which are close to a spatially uniform distribution of the quasi particles as far as the coordinates are concerned, and to a random distribution as far as the velocities are concerned, i.e., to states near the ground state. In that case the momenta of the collective motions (motions of a hydrodynamical character) will be small and the operator $\epsilon_j(\hat{\mathbf{p}})$ can be written in the form $\epsilon_j(\hat{\mathbf{p}}_0 + \hat{\mathbf{p}})$, where $\hat{\mathbf{p}}$ is the operator of the momentum of the collective motion (a small quantity) and $\hat{\mathbf{p}}_0$ the operator of the momentum of the random motion. Expanding ϵ_j in powers of $\hat{\mathbf{p}}$ and limiting ourselves to terms quadratic in $\hat{\mathbf{p}}$, we obtain

$$\varepsilon_j(\hat{\mathbf{p}}_0 + \hat{\mathbf{p}}) = \varepsilon_j(\hat{\mathbf{p}}_0) + \frac{1}{2}[\nabla_{\mathbf{p}_0}\varepsilon_j(\hat{\mathbf{p}}_0), \mathbf{p}]_+ + \frac{1}{4}[\Delta_{\mathbf{p}_0}\varepsilon_j(\hat{\mathbf{p}}_0), \hat{\mathbf{p}}^2]_+ + \cdots, \qquad (3)$$

where $[\,,\,]_+$ denotes an anticommutator.

We introduce into the wave function the new variable $\mathbf{r}_0$, canonically conjugate to $\hat{\mathbf{p}}_0$. If we assume that the commutator $[\hat{\mathbf{p}}_0, \hat{\mathbf{p}}]_- = 0$, then $\psi_j = \psi_{0j}(\mathbf{r}_0)\Phi_j(\mathbf{r})$. Substituting (3) into (2) and averaging over the functions $\psi_{0j}(\mathbf{r}_0)$ which satisfy the equation

$$\varepsilon_j(\hat{\mathbf{p}}_0)\psi_{0j} = \varepsilon_{0j}\psi_{0j}, \qquad (4)$$

we obtain the equation

$$-\frac{\hbar^2}{2m_j^*}\Delta\Phi_j - i\hbar(\mathbf{v}_j^0\nabla)\Phi_j + \int G(|\mathbf{r}-\mathbf{r}'|)\sum_i |\Phi_i(\mathbf{r}')|^2 d\mathbf{r}'\Phi_j = (\varepsilon_j - \varepsilon_{0j})\Phi_j, \qquad (5)$$

in which we have used the notation

$$1/m_j^* = \int \psi_{0j}^*\Delta_{\mathbf{p}_0}\varepsilon_j(\hat{\mathbf{p}}_0)\psi_{0j}d\mathbf{r}',$$

$$\mathbf{v}_j^0 = \int \psi_{0j}^*\nabla_{\mathbf{p}_0}\varepsilon_j(\hat{\mathbf{p}}_0)\psi_{0j}d\mathbf{r}', \quad \varepsilon_{0j} = \int \psi_{0j}^*\varepsilon_j(\hat{\mathbf{p}}_0)\psi_{0j}d\mathbf{r}'.$$

Equation (5) obtained in this way describes only the collective motions in a system of quasi particles, but its coefficients depend on the characteristics of the random motion of the quasi particles in the ground state determined by Eq. (4).

Substituting into (5)

$$(\varepsilon_j - \varepsilon_{0j}) \to i\hbar\partial/\partial t, \quad \Phi_j = (1+\rho_j)^{1/2}e^{iS_j/\hbar}$$

(Φ_j is normalized in a unit volume), and retain-

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*Taking exchange interaction into account gives, for instance, in the case of Coulomb forces,

$$\varepsilon(p) = \frac{e^2}{\pi\hbar}p_0\left(2 + \frac{p_0 - p}{p_0 p}\ln\frac{p_0 + p}{p_0 - p}\right)$$

(p_0 is the momentum at the Fermi surface); taking force correlations into account leads to a more complicated dependence $\varepsilon(p)$.

ing in the equations for ρ_j and S_j the terms linear in S_j and ρ_j, we get

$$S_j + (\mathbf{v}_j^0 \nabla) S_j + \int G(|\mathbf{r}-\mathbf{r}'|) \sum_i \rho_i(\mathbf{r}')\, d\mathbf{r}' - (\hbar^2/4m_j^*)\Delta\rho_j = 0, \quad (6)$$

$$\rho_j + (\mathbf{v}_j^0 \nabla)\rho_j + (1/m_j^*)\Delta S_j = 0.$$

For solutions of ρ_j and S_j of the form $\sim \exp[i(\mathbf{k}\cdot\mathbf{r}) - i\omega t]$ these equations lead to the following dispersion relation

$$1 = k^2 G(k) \sum_j \frac{1}{m_j^*} \left\{ (\omega - \mathbf{v}_j^0 \cdot \mathbf{k})^2 - \frac{\hbar^2 k^4}{4m_j^{*2}} \right\}^{-1}. \quad (7)$$

From (7) it follows that in the limit as $\mathbf{k} \to 0$ the frequency ω_0^* depends on the effective mass of the quasi particles which, generally speaking, differs from the ordinary mass of the particles.

In the case where $\epsilon(p) = p^2/2m$, (7) goes over into the well-known dispersion law.[1] To evaluate m_j^* it is sufficient to know the dependence of the total energy (kinetic Fermi, exchange, and correlation energy) of one particle on its momentum. In the case of a dense electron gas $\epsilon(p)$ can be evaluated by the method given in Ref. 2.

The method proposed here is suitable to find the spectrum of the plasma oscillations of electrons in a periodic field, for the case of one band.† If we understand by $\epsilon_{0j}(p_0)$ the energy of an electron in a periodic field, then Eq. (7) is equivalent to the corresponding equation in the paper by Wolff.[3]

[1] D. Pines, Phys. Rev. **92**, 626 (1953).
[2] M. Gell-Mann and K. A. Brueckner, Phys. Rev. **106**, 364 (1957); M. Gell-Mann, Phys. Rev. **106**, 369 (1957).
[3] P. A. Wolff, Phys. Rev. **92**, 18 (1953).

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CREATION OF POSITIVE PIONS BY NEGATIVE PIONS

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THE creation of pions by pions has been studied by a number of authors.[1-6] All these analyses refer to the creation of pions in the nucleus as a whole; one may assume, however, that at these incident energies, the pions are created on the individual nucleons of the nucleus. The effect of the nucleus manifests itself in this case through a second-order interaction between pions of the final state and the nucleons of the nucleus. This circumstance considerably complicates the interpretation of experimental data, and therefore we can only obtain from it the qualitative character of the creation of pions by pions.

In the present article we consider the creation of positive pions in nuclear emulsion under the action of negative pions having an energy of 340 ± 30 Mev.

The emulsion stack consisting of 60 layers of NIKFI type R emulsion, of 23 mm total thickness and 100 mm diameter was placed in the 370-Mev negative pion beam of the synchrocyclotron of the Joint Institute for Nuclear Research. In passing through the emulsion, the incident pions lost up to 60 Mev by ionization. Thus the present results describe the creation of pions under the influence of negative pions having an energy $E_0 = 340 \pm 30$ Mev. The method chosen to find cases of positive pion production consists in area scanning the emulsion and counting $\pi^+ \to \mu^+ \to e^+$ decays. Then the positive pions were followed to their creation point. This search method effectively allowed us to count the production of pions leaving a path of up to 6 cm, i.e., an energy up to 70 Mev.

In following positive pion tracks, 56 stars caused by negative pions were found. In 21 of these stars the emission of the positive pions was accompanied by the emission of a second meson identified by the grain density gradient along the track. It is evident that these events must be attributed to the formation of the positive pion. The emission of a second pion was not found in the remaining stars, but these events can again be attributed to the formation of positive pion followed by the absorption of the negative pion by the nucleus, or the emission of a neutral pion. This conclusion is supported by data on the absorption of pions by nuclei at these energies.[7]

*The method developed to find the dispersion equation is easily generalized to cover the case of many bands.