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EXCHANGE OF ENERGY BETWEEN COLLECTIVELY-INTERACTING BEAMS OF POSITIVE AND NEGATIVE IONS

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We report here the first experimental observation of the effect of exchange of energy between beams of charged particles in a system of mutually penetrating beams of positive and negative ions producing a quasi-neutral synthesized plasma. The different signs of the interacting particles make it possible to analyze separately their velocity distribution functions in the same velocity interval (such an analysis is impossible in the case of charged particles having the same sign).

Mutually penetrating beams of positive and negative hydrogen ions with a current of ~ 2 mA each and an energy ~ 13 keV passed through an interaction chamber of 120 or 220 cm length, with a Hughes-Rojansky analyzer placed at the end of the chamber. At a fixed average beam velocity $v_0 \approx 1.6 \times 10^8$ cm/sec, it was possible to vary their relative velocity by an amount $2\Delta v$ ($\Delta v \ll v_0$), leading to a strengthening of the oscillations as a result of the development of drift two-stream instability, the linear stage of which was investigated in [1]; the same reference describes the experimental setup. On entering the chamber the beams were velocity modulated with the aid of three grids such that $\tilde{v}_1(0) = -\tilde{v}_2(0) = \tilde{v}(0)$, the amplitude of the alternating component of the velocity being $\tilde{v}_0 \ll \Delta v$; the modulation frequency was f = 112 MHz.

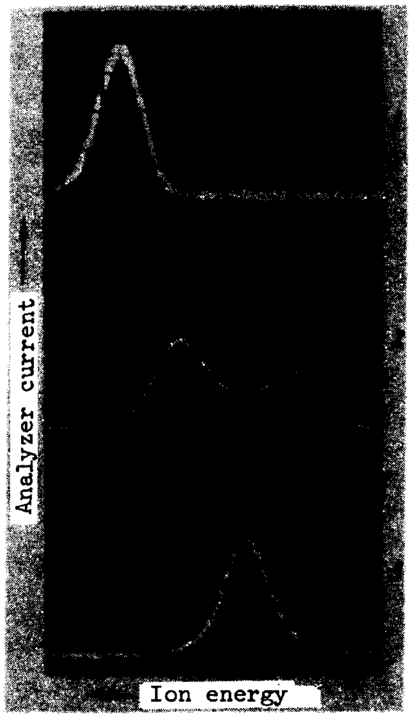

Fig. 1. Oscillograms of analyzer current for particles of one beam: 1 - $\Delta v > \Delta v_{cr}$, 2 - $\Delta v = \Delta v_{opt}$, 3 - $\Delta v = 0$. L = 220 cm, $\tilde{v}_0/\Delta v_{opt} = 0.3$.

Figure 1 shows oscillograms representing the time-averaged particle energy distribution function in one of the beams for three different values of Δv: $\Delta v = 0$, $\Delta v > \Delta v_{cr}$ (no amplification), and $\Delta v = \Delta v_{opt}$ (maximum amplification). We see that at the optimal relative velocity the collective interaction leads to an appreciable change in the distribution function. Figure 2 shows analogous distributions for both beams at $\Delta v = \Delta v_{opt}$ for different values of the amplitude of the initial modulation and interaction length.

The presented data enable us to draw the following conclusions concerning the character of variation of the observed beam particle distribution function: 1) When the amplitude of the initial modulation exceeds a certain value (which depends on the interaction length L), an asymmetrical distortion of the distribution function of each of the beams takes place, thus indicating that the collective interaction has a nonlinear character. 2) The distribution function of each of the beams broadens in the direction of the energy of the

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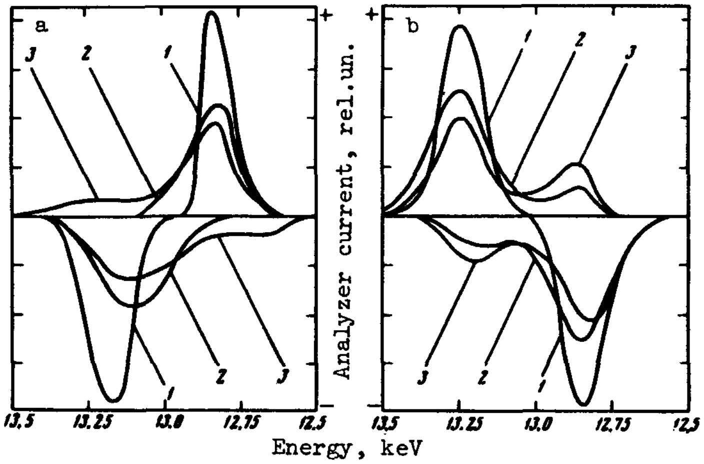

Fig. 2. Particle energy distribution functions of both beams at $\Delta v = \Delta v_{opt}$; 1 - $\tilde{v}_0/\Delta v = 0$, 2 - $\tilde{v}_0/\Delta v = 0.15$, 3 - $\tilde{v}_0/\Delta v = 0.3$; a - L = 120 cm, b - L = 220 cm.

second beam independently of the sign of the relative velocity (thus, the fast beam is that of the negative ions in Fig. 2a and of the positive ions in Fig. 2b). Thus, the energy of the fast beam decreases on the average and that of the slow one increases, i.e., energy exchange takes place between the interacting beams. 3) At sufficiently large amplitude of the initial modulation $\tilde{v}_0$ and at a large interaction length L, a second maximum is produced on the distribution function of each of the beams; the position of this maximum corresponds to the initial energy of the second beam; when the second maximum is produced, the energy spectrum of the beam particles becomes somewhat narrower.

Let us compare the interaction length at which an asymmetry of the distribution function appears with the distance z_{ph} over the phase bunching of the beam particles should occur, with allowance for their collective interaction. We determine the position of the phase focus z_{ph} from the condition $\tilde{v}(z_{ph}) \simeq \Delta v$ (see [2]) (here $\tilde{v}_0 << \Delta v$), assuming that up to the phase focus the spatial amplification of the oscillations is exponential

$$\tilde{v}(z) \approx \frac{1}{4} \tilde{v}_0 \exp \gamma z$$

with a linear increment $\gamma = 0.5\omega_p/v_0$ (at $\Delta v = \Delta v_{opt}$):

$$z_{ph} \approx \frac{2v_0}{\omega_p} \ln \frac{4\Delta v}{\tilde{v}_0}.$$

Under the conditions of our experiment ($\omega_p = 6.3 \times 10^6$ rad/sec, $\tilde{v}_0/\Delta v = 0.07$) this estimate leads to a value z_{ph} = 200 cm, which is in satisfactory agreement with the experimentally observed length L = 220 cm. We note that the change of the energy spectrum of the beam, and also the formation of a second maximum on the distribution function, is in qualitative agreement with the results of a numerical calculation of the nonlinear interaction of two electron beams [3].

Thus, the observed effect of exchange of energy between beams of positive and negative ions is the consequence of a nonlinear interaction resulting from phase bunching of the particles during the course of the development of the two-stream instability.

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MAGNETIC ANOMALIES OF THE THERMAL EXPANSION OF CHROMIUM

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The great attention paid presently to the electric and magnetic properties of chromium is connected mainly with a number of features of its electron configuration. Thus, from the point of view of the band structure, the electron configuration d^5s^1 corresponds to the region of the transition from Pauli paramagnets (BCC metals of subgroups IVa and Va of the periodic system) to antiferromagnets (BCC metals of subgroup VIIa). The fact that chromium is actually in the transition region is evidenced, for example, by the relatively small magnetic moment per atom ($\sim 0.4\ \mu_B$) and the strong sensitivity of the Neel point to impurities [1], namely, small admixtures of vanadium decrease T_N sharply, and the presence of less than 0.5 at.% Mn in chromium leads to a sharp increase of T_N from 311 to 475°K. It is interesting that manganese contributes in this case to stabilization of the antiferromagnetic structure of chromium [2].

A number of recent papers offer evidence of the existence of anomalies in the variation of the parameters of the crystal lattice of chromium (and of the macroscopic dimensions of the sample as a whole) when magnetic ordering sets in [3 - 5]. We have therefore undertaken a direct x-ray structure determination of the dependence of the chromium lattice parameters on the temperature.

Chromium has a cubic body centered lattice assumed to have orthorhombic distortions in the temperature region $120 < T < 311°K$ and tetragonal distortions at $T < 120°K$ [6]. Carefully performed x-ray diffraction investigations have shown, however, that the relative magnitudes of these distortions $\Delta a/a$ does not exceed 10^{-5}, so that they cannot be observed by ordinary x-ray methods [7]. (We note that this result agrees with the results of a study of the shapes of the diffraction maxima at different temperatures in our investigation.)

The investigations were carried out with a sample containing not more than 0.018% of impurities (not more than 0.010 and 0.008% of nitrogen and oxygen, respectively); the sample was relieved of mechanical stress by electrochemical etching.

During the measurements, the temperature of the sample was maintained automatically with accuracy not worse than 0.05°. Prior to the measurement, the sample was held at each temperature not less than 2 - 3 hours. To increase the calculation accuracy, the (112) diffraction peak was plotted point by point (in steps of 2' - 3').

The results of the calculation of the lattice parameter a at the different temperatures are shown in the figure. It is seen from the figure that there are two regions of anomalous variation of the chromium lattice parameters: when magnetic ordering appears (near T_N) and below the temperature T_{SF} of the phase transition connected with the change in the character of the magnetic order. It is obvious that both anomalies on the a(T) plot are due to the appearance of