and to inaccuracies of the thermodynamic composition of the plasma, is marked by horizontal bars in Fig. 4.

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Shock-wave production of a non-ideal plasma

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Experiments on generation of a non-ideal argon or xenon plasma by intense shock waves are described, and results of investigation of the equation of state of the plasma are presented. The experiments are performed with explosive generators of rectangular shock waves in which condensed explosives are employed as the active elements. A thermodynamically complete equation of state of the imperfect plasma is determined by recording the kinematic parameters of the shock wave and the temperature. The equation is compared with theoretical models.

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1. INTRODUCTION

The thermodynamic properties of a dense low-temperature plasma with strong interparticle interaction is presently the object of intensive theoretical and experimental research.[1] This is due to the need for a physical analysis and hydrodynamic calculation of the phenomena caused by intense pulsed energy release in dense media, which are the basis for the development of various prospective designs and devices.[2] At the same time, a non-ideal plasma occupies an extensive region of the phase diagram of matter, in which strong electrostatic interaction is decisive and can lead to various and qualitatively new physical phenomena and effects.[1]

In view of the considerable mathematical difficulties, the possibilities of a pure theoretical study of strongly interacting disordered electron-ion systems are quite limited, and to describe them thermodynamically it is necessary for the time being to resort to model considerations. Heuristic models of this type[1] are in fact extrapolations of ideas about the role of quantum and collective effects in Coulomb interactions, originally developed for the weakly non-ideal region, and the results are therefore highly uncertain. Much more advanced and physically more meaningful model approaches are based on the use of the Monte Carlo method, [3] where the main hypotheses concern the form of the electron-ion pseudopotential, the proper choice of which calls in final analysis for the use of experimental materials.

Generation of a non-ideal plasma calls for concentration of an appreciable energy in dense media, a fact that raises the main experimental difficulties of such investigations. Pulsed methods of Joule and electromagnetic heating lead to the development of various instabilities in the plasma, and are furthermore restricted to energy levels presently attainable under laboratory conditions ($\sim 10^6$ J/pulse), so that the required states can be generated in small and frequently strongly inhomogeneous volumes. A more effective way of obtaining and investigating the thermodynamic properties of a non-ideal plasma is to use dynamic methods, [4,5] in which shock waves cumulate the energy in the investigated substance. The highest and controllable parameters of the plasma can be attained in this case by using high-power condensed explosives as active elements, in view of their high ($\sim 10^4$ J/cm^2) energy content and in view of the detailed studies already made of high-velocity detonation and hydrodynamic characteristics of explosive sweeping devices. [6] In addition modern technology of active explosive charges and the possibility of producing high-velocity propelling systems[6] make it possible to organize the process of plasma generation with constant parameters for a time $\sim 10^{-6}$ sec in a space measuring several millimeters, which is sufficient to perform the measurements with acceptable accuracy.

In stationary flow, the determination of the thermodynamic characteristics of a shock-compressed medium reduces, on the basis of first principles of mechanics, to measurement of the kinetic parameters of the motion of the shock wave, and this is an additional significant advantage in view of the fact that methods for the diagnostics of a dense plasma have not been sufficiently developed. At the present time dynamic methods are the main source of extensive information on the properties of condensed media at extremely high pressures and temperatures. [6] The use of dynamic methods in plasma physics has made it possible to investigate the shock compressibility of cesium[4] and argon[5] plasmas and to determine on this basis the phase composition and the complete thermodynamic equation of state of a nondegenerate plasma in a wide range of non-ideality parameters $\Gamma = e^3(8\pi n_e)^{1/2}/kT^{3/2} \sim 0.1-2.5$. The parameters of shock compression of argon were obtained also by Gristian and Yarger[7] and by Zhernopletov *et al.*[8] The electroconductivity of a strongly compressed plasma of neon, argon or xenon was measured with an explosive shock tube, [9] and this yielded information on the Coulomb component of the electric conductivity at $\Gamma \sim 0.3-4.5$.

The present paper is devoted to the generation and study of the thermodynamic properties of a dense plasma of argon and xenon by dynamic methods based on compression, heating, and acceleration of gases in the front of a high-power ionizing shock wave. [6,10] The object of the investigation was chosen to be argon or xenon, in view of the fact that no molecular and ion-molecular formations are produced, the detailed studies of the elementary processes, and the large molecular weight, which makes for effective heating of these gases by shock waves. To produce plane rectangular shock waves we used explosive generators, the action of which is based on acceleration of metallic strikes by the detonation products of high-power condensed explosives. We used electric-conduct and optical-basis methods of recording the kinematic parameters of the motion of the shock wave, which made it possible to determine the caloric equation of state of a non-ideal plasma behind the front of a shock discontinuity. Measurement of the equilibrium temperature of a shock-compressed plasma was by an optical brightness method.

2. DYNAMIC PLASMA COMPRESSION

The thermodynamic calculations of the parameters of a shock-compressed plasma have shown[11] that the optimal, in the sense of an appreciable plasma non-ideality, conditions of dynamic experiment correspond to shock-velocities $D \sim 5\times10^5$ and $\sim 9\times10^5$ cm/sec in xenon and argon, respectively. Further increase of D decreases the relative interparticle interaction Γ, in view of the stronger increase of the kinetic energy kT in comparison with the slowed-down increase of the electron density n_e during the concluding stages of the ionization.

To realize this range of shock-wave velocities in precompressed gases, linear generators of high-power rectangular shock waves were developed[6] with different intensities and durations. The active elements in these generators were high-power condensed explosives, in view of their high specific energy content and the speed of the detonation energy release, which lead to experimental setups of appreciable power and to convenience in the organization of a specified gasdynamics of the flow.

The linear shock-wave generator is illustrated in Fig. 1. The cylindrical active explosive charge consists of a specially shaped detonation lens 1, which applies a plane detonation front to the main charge 2 from a high-voltage detonator capsule. The striker 3, which is an aluminum or Plexiglas disk inserted in a steel mount and 2 or 7 mm thick, respectively, is accelerated by the expanding detonation products of the active charge 2. The 2-mm aluminum screen of the experimental assembly 4 with target 5 is stricken at a distance 2.5 cm from the charge, where the striker acquires a constant velocity and the detonation-induced wave processes in the striker have already relaxed. The experiments have shown that the explosive propelling devices have dynamic parameters that are reproducible within 1–2% for asynchronism of the motion of the driving shock wave in the target not worse than 10^{-7} sec. The intensity and duration of the shock waves generated in the plasma were varied by using explosive systems with different dimensions and with different shattering ability, and also by varying the material and thickness of the striker. The

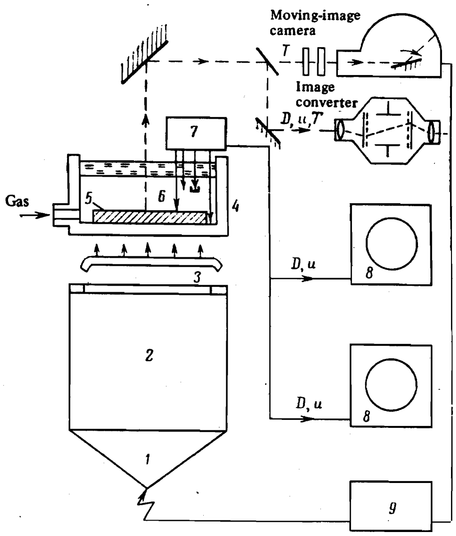

FIG. 1. Experimental setup: 1—detonation lens, 2—explosive charge, 3—metallic striker, 4—experimental assembly, 5—target, 6—investigated gas, 7—electric contact and pulse-shaping block, 8—oscilloscopes, 9—synchronization and explosion block.

highest plasma parameters were obtained with a propelling device that accelerated, as a result of detonation of a TG-30/70 alloy, a 2-mm aluminum striker to a velocity 5.92×10^5 cm/sec. The total energy released in this experiment was $\sim 25\times10^6$ J at a power level $\sim 10^{11}$ W.

The collision of the striker accelerated in this manner with the metallic target led to the formation in the latter of a shock wave with a pressure on the order of 10^6 bar. When this shock wave emerges to the free surface, the target material begins to expand in a centered relaxation wave, which in turn leads to generation of a new shock wave causing acceleration, compression, and irreversible heating of the investigated gas contained in the high-pressure assembly.

The velocity capabilities of the developed generators were further increased by using targets of strongly-compressible polymer materials (polystyrene, Plexiglas), and also by using the evaporation of the target material in an isentropic relaxation wave.[12] In the latter case, the use of targets of porous lead and copper made it possible to increase the shock wave velocity in the gases by 30–50%.

3. DIAGNOSTICS OF SHOCK-COMPRESSED PLASMA

The dynamic procedure for determining the equation of state of a shock-compressed medium is based on an independent determination of two kinematic parameters that characterize the propagation of a stationary shock discontinuity in the investigated medium.[6,10] In the process studied, the actual measurements consisted of recording the velocity D of the shock-wave front and of the mass velocity u, followed by the use of the conservation laws to determine the thermodynamic parameters of the plasma.

An essential requirement of this procedure is that the gas dynamic plasma flow be stationary in the registration zone, since this makes it possible, when the results are interpreted, to use the conservation laws in a simple algebraic form, rather than a complex system of differential equations. To this end, for each experimental situation (initial gas pressure and type of propellant), gasdynamic calculations were made of the propagation of the shock wave and of the distorting relaxation waves from the elements of the explosive generator and the experimental assembly. The inhomogeneities due to lateral relaxation waves were eliminated by using a striker and a target in the form of thin wide disks (thickness to diameter ratio ~ 0.05). The correctness of this type of calculation was monitored in a special series of experiments by varying the measurement base. In addition, the results of the optical measurements (see Fig. 2) together with the temperature afford an additional possibility of determining the perturbations that come from the rear and lateral surfaces. In all the experiments the measurement base was chosen in accordance with results of methodological experiments and hydrodynamic calculations.

In the experiments we used two methods of base-dependent velocity registration—an electric contact method[6] and an optical method.[8] The use of a system of uncovered electric-contact pickups has made it possible to register, with high-speed oscilloscopes, the shock-wave front velocity D with accuracy $\sim 1\%$.

The mass velocity u of the material was measured with electric-contact pickups of special construction, covered with metallic foil, which did not respond to the shock wave in the plasma and operated at the instant of arrival of the heavy contact surface of the target moving with velocity u.[1)] The operating quality of these pickups was estimated by varying their masses in a special series of experiments, and also by comparing the results of measurements by optical[8] and x-ray[5] procedures. In addition, methodological experiments were performed with helium, where in view of the low degree of ionization the uncovered and enclosed pickups operated simultaneously at the instant of arrival of the contact boundary. As a result of this comparison, the error in the registration of u is estimated at 1.5–2%. A system of two pairs of electric-contact pickups was placed in the measurement assembly in such a way as to take into account the possible tilt of the shock-wave front and to

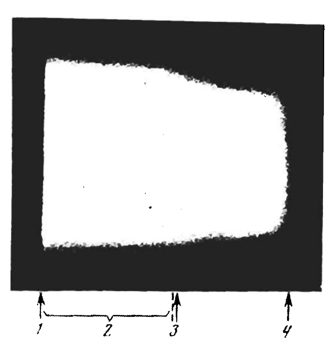

FIG. 2. Sweep of the glow of a shock-compressed plasma: lateral and rear relaxation waves.

avoid the influence of lateral relaxation waves. A special pickup was used to measure the velocity of the shock wave in the target, in order to monitor the reproducibility of the parameters of the driving pulse from the explosive generator. The electric signals generated by the pickups were fed through independent channels to high-speed OK-15 oscilloscopes with spiral beam sweeps.

At high initial xenon pressures, the density of the shock-compressed plasma becomes comparable with the density of the material of the expanding targets, and this leads to instabilities in the operation of the enclosed electric contacts. The measurement of the wave and mass velocities is performed in this case by the optical-basis method.[8] A Plexiglas partition is placed in the experimental assembly at a given distance from the target, and the plasma radiation passing through this partition is registered. The emergence of the shock wave from the target into the investigated gas leads to the appearance of plasma glow, which is amplified when the shock wave is reflected from the partition. This instant of time determines the velocity of the shock-wave front. When the intense shock wave reflected from the target arrives at the partition, the Plexiglas loses its transparency and the plasma radiation is cut off, and this determines the mass velocity u. The optical measurements were performed with the Imakon-H.E.-700 image converter, the entrance slit of the optical system of which was mounted along the diameter of the experimental assembly 4. The image scanning rate in the moving-image-photography regime was 0.50–1 μsec/cm.

To measure the temperature of the shock-compressed plasma we used a brightness method[13,14,5] based on photography of the intense optical radiation from the shock-wave front (see Fig. 1). The equilibrium plasma temperature was determined by photometric comparison of the photographic density of the time-scanned (with the aid of the streak camera SFI-2M) glow of the shock-compressed plasma and standard light sources. The radiation sources were a pre-calibrated FPK-50 flash lamp with brightness temperature $T = 8600 \pm 200\,^\circ$K, the capillary flash lamp EV-45 with $T = 39\,000 \pm 700\,^\circ$K, and a shock wave in air with $T = 11\,800 \pm 600\,^\circ$K. The use of a neutral optical step wedge when photographing the standard made it possible to cover the entire density range expected in the experiment. To ensure that the density lies in the linear section of the characteristic curve of the photographic film, calibrated neutral wedges were used. To eliminate the effect of the photochemical development on the results of the measurements, the films of each run of experiments and the standards were developed simultaneously.

The results of the temperature measurements can in principle be distorted by the screening action of the gas layer, heated with ultraviolet radiation from the shock-compressed plasma, ahead of the shock-wave front.[10] The available experimental[14,15] and theoretical[10] data show, however, that the screening of the radiation of strong shock waves comes into play noticeably in argon starting with $D \gtrsim 22 \times 10^5$ cm/sec and in xenon starting with $D \gtrsim 12 \times 10^5$ cm/sec, and decrease with increasing initial gas pressure.

The experimental setup (Fig. 1) makes it possible to monitor, besides the temperature, the optical density of the shock-compressed plasma in each experiment, by tracing the increase of the radiation intensity with time. In all the regimes, the optical thickness turned out to be beyond the limits of the resolution of the SFR-2M moving-image camera, and did not exceed 10^{-2} cm, so that when the plasma temperature is calculated it can be assumed that the shock-wave front is an absolute black-body radiator. The principal periods of measurements were performed at the wavelength 5800 ± 50 Å, separated with an interference light filter. In view of the appreciable number of employed standards and the good reproducibility of the experiments, the accuracy with which the brightness temperature of the shock-compressed plasma was registered is estimated at 5–10%, as is confirmed by experiments aimed at measuring the temperature of air, and also by a series of control experiments with argon and xenon at a wave length 4950 ± 50 Å.

To verify the diagnostic methods employed here, we recorded the kinematic and brightness characteristics of the shock waves in air at atmospheric pressure, for which, in view of the small deviation of the plasma from ideal, reliable thermodynamic calculations[16] and detailed measurements[14,17,18] are available. The obtained data (Fig. 3) show that within the limits of the errors indicated above the calculated and experimental results are in agreement.

4. EXPERIMENTAL RESULTS

The equation of state of the shock-compressed plasma was determined by a dynamic method based on measurements of the kinematic characteristics of the propagation of the shock discontinuity. In analogy with dynamic compression of condensed media,[6] the actual measurements for the plasma consisted of a basis-method registration of the front velocity D and of the mass velocity u of the material.

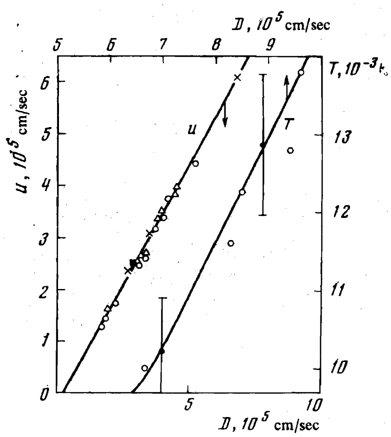

FIG. 3. Registration of the parameters of shock-compressed air. Solid curve—calculation in accordance with [16], ∇—[17], ○—[18], ×—probe measurements, ■—optical registration (image converter). Temperature data: ○—[11]; ●—our measurements.

TABLE I. Comparison of theoretical and experimental data.

Gas	Experiment							Theory							
								P, H=const				P, T=conts			
	P_0, bar	$D\cdot10^{-5}$, cm/sec	$U\cdot10^{-5}$, cm/sec	$P\cdot10^{-3}$, bar	V, cm³/g	$H\cdot10^{-10}$, erg/g	$T\cdot10^{-3}$, K	V, cm³/g	$T\cdot10^{-3}$, K	$n_e\cdot10^{-20}$, cm⁻³	Γ	V, cm³/g	$H\cdot10^{-10}$, erg/g	$n_e\cdot10^{-20}$, cm⁻³	Γ
Ar	1	6.61	5.68	0.62	85.8	21.6	—	80.1	19.6	0.42	0.81	—	—	—	—
	3	6.36	5.47	1.71	28.3	19.9	18.0	28.7	20.3	0.93	1.15	23.9	13.9	0.55	1.05
	3	2.80	2.10	0.29	48.4	3.70	—	52.0	7.11	$6\cdot10^{-5}$	0.04	—	—	—	—
	5	5.26	4.16	1.79	25.5	13.2	19.7	22.4	17.8	0.54	1.06	26.0	18.0	0.85	1.15
	15	5.67	4.73	6.59	6.69	15.6	18.7	6.92	20.0	2.15	1.77	6.31	13.3	1.55	1.67
	15	2.33	1.73	1.02	9.60	2.79	—	10.8	5.21	10^{-6}	0.01	—	—	—	—
	25	5.50	4.40	9.92	4.83	14.7	19.0	4.49	19.8	2.68	2.01	4.24	13.2	2.18	1.93
	50	2.80	2.11	4.84	3.01	3.83	—	3.24	7.40	10^{-4}	0.10	—	—	—	—
	50	5.36	4.10	18.0	2.88	13.7	18.5	2.42	19.7	3.85	2.423	2.24	11.9	2.77	2.26
Xe	3	1.96	1.58	0.50	12.1	1.90	—	14.1	10.8	0.05	0.71	—	—	—	—
	3	3.83	3.33	2.07	8.15	7.27	—	7.30	19.0	2.00	1.85	—	—	—	—
	3	5.22	4.51	3.85	7.70	13.4	23.5	6.51	25.9	4.86	1.83	5.47	10.9	4.56	2.04
	10	5.10	4.38	12.1	2.62	12.8	25.5	2.09	27.2	1.42	2.89	1.86	11.0	13.6	3.11
	15	3.92	3.29	10.4	1.98	7.52	20.6	1.64	21.6	9.60	3.34	1.51	6.61	8.61	3.40
	20	4.14	3.50	15.6	1.43	8.41	20.8	1.19	23.1	14.9	3.76	1.00	6.39	11.9	3.94
	50	3.96	3.13	33.4	0.78	7.54	22.4	0.55	23.4	29.1	5.16	0.51	6.96	25.2	5.13

The use of the mass, momentum, and energy conservation laws for a stationary shock discontinuity makes it possible to determine in each experiment the pressure P, the specific volume V, and the enthalpy H:

$$P=P_0+\frac{1}{V_0}Du,\quad V=V_0\frac{D-u}{D},\quad H=H_0+u\left(D-\frac{u}{2}\right),\qquad (1)$$

which is the case of a non-ideal plasma have a clear physical meaning and can be directly recorded. In the employed balance relations (1) we have neglected the radiant energy transport, the role of which is usually small.[10] Actual estimates of the emission from an argon or a xenon plasma are contained in[19].

It is seen from (1) that the pressure and enthalpy of the medium are determined directly by the velocities D and u, whereas the specific volume V depends on the difference of these quantities. Therefore the errors in the determination of the specific volume of a strongly compressed plasma by means of (1) are larger than in dynamic investigations of condensed media.[2)] At the same time, in view of the considerable indeterminacies of the theoretical models, the realized measurement errors are quite acceptable for the determination of the influence of the Coulomb interaction on the thermophysical properties of the plasma. Registration of the equilibrium temperature of a shock-compressed plasma together with kinematic measurements of the caloric equation of state in accordance with (1) makes it possible to obtain in each experiment information on the thermodynamically complete equation of state of a shock-compressed non-ideal plasma.

The obtained experimental data are listed in Table I, where each experimental point is the result of averaging five–eight experiments consisting of two–three independent registrations each. The temperature measurements were performed for states with an appreciable electrostatic interaction, where noticeable deviations from the theoretical models were expected.

Let us estimate the expected measurement errors. The errors in P_0 (initial vacuum ~ 10^{-1} mm Hg) and T_0, amounting to 1%, correspond to an uncertainty ~ 1.5–2% in V_0 and H_0, while an error of 1% in D and 1.5–2% in u introduces the following uncertainty in the quantities contained in the conservation laws (1) at $\sigma = V_0/V \sim 5$–10:

$$\delta V=[\delta V_0^2+(\sigma-1)^2\delta D^2+(\sigma-1)^2\delta u^2]^{1/2}\sim7-18\%,$$
$$\delta P=[\delta V_0^2+\delta D^2+\delta u^2]^{1/2}\sim2-3\%,$$
$$\delta H=\left[\frac{4}{(\sigma+1)^2}\delta u^2+\frac{4\sigma^2}{(\sigma+1)^2}\delta D^2\right]^{1/2}\sim3-5\%.$$

When comparing the results of the experiments with the non-ideal plasma theories at fixed P and H or P and T, the entire measurement error is referred to V and amounts to

$$\delta V_H=(\delta V^2+\delta P^2+\delta H^2)^{1/2}\sim7-20\%,$$
$$\delta V_T=(\delta V^2+\delta P^2+\delta T^2)^{1/2}\sim8-20\%.$$

The experiments were performed at initial gas pressures up to 50 atm, determined by the construction features of the experimental assemblies and by the possibility of generating shock waves of sufficient intensity. The velocities D attained in the experiments in the case of xenon are close to optimal and are determined by the velocities attainable with the employed explosive sweeping system. In addition, at these parameter values, in view of the absence of noticeable screening,[10] the darkness temperatures of the shock-compressed plasma can be recorded.

Figure 4 shows a comparison of the data of Table I with theoretical calculations[19] and with results of registration of the shock adiabats of argon by x-ray diffraction[5] and optical[8] methods. For an approximate description of the states with $u \gtrsim 2$–2.5 km/sec (where

TABLE II. Values of the parameters of the approximate expression (2).

P_0, bar	A, 10^5 cm/sec	B
1	1.639	0.955
5	0.826	1.044
15	0.203	1.175
25	0.166	1.206
50	0.058	1.231

the ionization is noticeable and the plasma effects are appreciable) we can use the approximation

$$D=A+Bu, \qquad (2)$$

which is employed for the presently investigated range of parameters in Fig. 4. The values of the constants A and B are listed in Table II. To monitor the obtained data, we used a gas-dynamic criterion,[6] according to which the shock-wave-generated plasma states lie in the $P-u$ plane on the curves of the isentropic expansion of the condensed targets of the explosive generator.

A comparison of the measurement results with the Debye approximation traditionally used for estimates[4,20] in a grand canonical ensemble is shown in Table I, where the calculated values are given for fixed P, H, or P, T corresponding to the values measured in the experiment.

Figure 5 shows a more detailed comparison of the experimentally measured thermodynamic parameters of the plasma (index 1) with a number of the most characteristic theoretical models: index 2—ideal plasma using converging quantum-mechanical expressions[21,20] for the partition functions of the discrete spectrum of the electrons; 3—Debye approximation in grand canonical ensembles[22]; 4—normalized Debye approximation using the conditions of local electroneutrality for the binary correlation function[22]; 5—Debye theory in the microcanonical ensemble of statistical mechanics[20]; 6—calculations by the Monte Carlo method of zero model of plasma with $\varepsilon=2$.[3] The employed polynomial approximation of the numerical calculations has made it

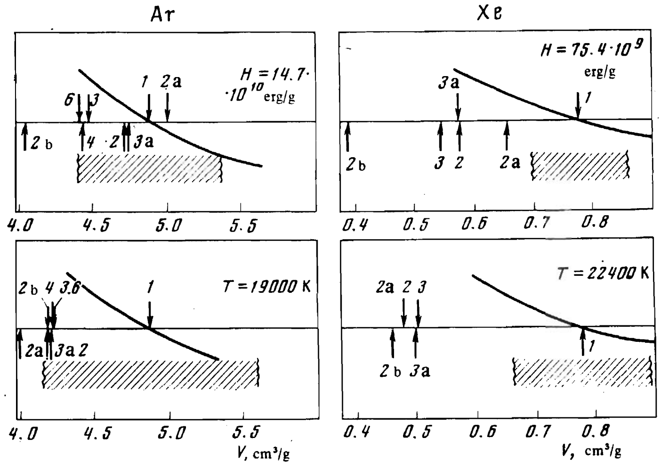

FIG. 5. Comparison of the experimental data with the theoretical models for an argon plasma ($P_0=25$ bar, $P=9.92\times10^3$ bar) and a xenon plasma ($P_0=50$ bar, $P=33.4\times10^3$ bar). The error corridor is shown shaded.

possible to calculate states up to $\Gamma\sim5$.

To analyze the contribution of different methods of limiting the partition function of the neutral particles, the thermodynamic functions of the plasma were calculated with account taken of only the energy ground state (index a) and without limitation of the partition function (index b)—100 energy levels were used.

An analysis of the experimental results show that in the region of low initial pressures P_0 (where the plasma deviates little from ideal) and small values of the velocities D (where the ionization is weak), the measurement data agree with the theoretical approximation. With increasing temperature and charge density, the interaction between particles in the system becomes stronger and the discrepancy between theory and experiment exceeds the limits of the expected measurement errors. The results are overestimated[4,5] in this case in comparison with the ideal-gas value of the pressure at constant H and constant T in a non-ideal partly-ionized plasma. An analysis based on the model equations of state has shown that the presently employed method of taking into account the interaction in the continuous and discrete spectra does not yield a noncontradictory description of the obtained data. Agreement can apparently be reached by taking into account the deformation of the discrete spectrum of the bound electrons, brought about by the strong interparticle interactions. Corrections of this type require, generally speaking, complicated self-consistent quantum-mechanical calculations (for the simplest results for hydrogen see[23]).

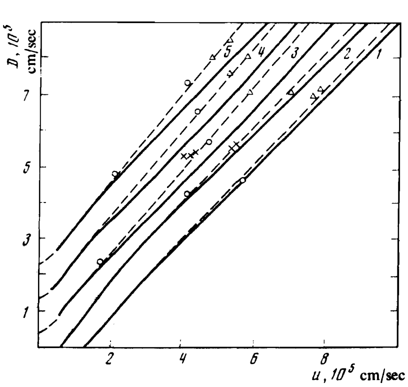

FIG. 4. Results of registration of shock adiabats of argon: 1) $P_0=1$ bar, 2) 5 bar, 3) 15 bar, 4) 25 bar, 5) 50 bar. For these initial pressures, the plots are shifted in the D direction by +2, −1, 0, +1, and +2 km/sec, respectively. Δ—[8], ×—[5], o—our data. Solid curves—calculated from[19], dashed—calculated from (2).

The obtained experimental data do not yield definite information on the phase stratification of a non-ideal plasma in the investigated range of parameters.

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[1)]We note that in our experiments, in view of the stationary character of the flow, the contact surface is not distorted by development of a Rayleigh-Taylor instability.

[2)]In a number of cases, direct registration of the plasma is possible by passing soft x rays through it.[5]

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Linear transformation of electromagnetic waves in the region of quasitransverse propagation in a three-dimensionally inhomogeneous magnetoactive plasma

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Transformation of circularly polarized waves in the region of a quasitransverse magnetic field in a three-dimensionally inhomogeneous electron plasma is investigated. Analytic expressions are obtained for the fields in the localized interaction region. The possibilities of determining the local electron concentration at the orthogonality point by measuring the transformation coefficient ("Cotton–Mouton" plasma diagnostics) are discussed.

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1. INTRODUCTION

The interaction of circularly polarized waves in a magnetoactive plasma in the region of quasi-transverse magnetic fields (we shall speak for the sake of brevity of a "quasi-transverse" interaction) has been used to explain the singularities of solar radio emission[1–3] (from among the latest studies we point out also[4]) and certain anomalies of the Faraday effect in the earth's ionosphere.[5,6] All the calculations of this effect were carried out so far for a simplified formulation of the problem: plane waves in a homogeneous plasma placed in an inhomogeneous magnetic field; the only analytic result obtained so far for the transformation coefficients is that of Zheleznyakov and Zlotnik[2] (see also[3]), who used the phase-integral method.

In this paper we report a method of describing the effect of quasi-transverse interaction in a three-dimensional inhomogeneous plasma, based on the quasi-isotropic approximation of geometrical optics (see[7], and also[8,9]), which is applicable to waves in weakly-anisotropic media, particularly to waves in a plasma situated in a weak external magnetic field H_0:

$$u=\omega_H^2/\omega^2=(eH_0/mc\omega)^2\ll 1. \qquad (1)$$

This method takes into account the bending and the tor-