EQUATION OF STATE OF A NONIDEAL CESIUM PLASMA

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Submitted December 31, 1971

Zh. Eksp. Teor. Fiz. 63, 92–103 (July, 1972)

Experimental results of a shock wave investigation of the equation of state of a nonideal cesium plasma in a heated shock tube are presented. Measurement of the velocity of the shock discontinuity front and the plasma density allows us to determine the equation of state in the caloric form $H = H(P, V)$, which is used to construct the isentropes and to compute the shock-compressed plasma temperatures. The results are compared with existing theories of plasma nonideality.

1. INTRODUCTION

Two circumstances have caused the recent revived interest in the thermophysical properties of plasma states with high charged-particle densities, when the behavior of the system is strongly influenced by the interparticle Coulomb interaction. The properties of a nonideal plasma are decisive in the realization of a number of power projects. The study of the nonideal plasma is undoubtedly of general physical interest, allowing us to obtain information about the properties of a substance in an as yet unexplored region of the parameters[1], as well as in connection with the possible appearance in a dense plasma of a number of interesting physical effects[2,3]. The possibilities of a purely theoretical investigation of a nonideal plasma are limited by difficulties in the selection of a small parameter for the subsequent application of perturbation theory in the quantum-mechanical many-body problem[1,4]. A promising direction of investigation of the nonideal plasma is the simulation of its properties by the Monte-Carlo statistical trial method, which does not employ expansion in powers of a small parameter in the computation of the statistical integral of the system under consideration[5]. At the same time the success of the application of this method for the computation of a real multi-component plasma is determined by the successful choice of a model pseudopotential for the interparticle interaction[6]. Heuristic methods[2,6], based on the model description of the collective and quantum effects of the Coulomb interaction, are of late being used for a qualitative analysis of the behavior of a plasma under conditions of strong nonideality. Being essentially an extrapolation, such a description yields very ambiguous results, although it predicts interesting physical effects. In particular, the question of a plasma phase transition—the stratification of a highly nonideal plasma into phases of different densities—is discussed in the literature in connection with the loss of thermodynamic stability with the aid of a number of model equations of state[2]. Under the conditions of great ambiguity of the theoretical predictions for a highly nonideal plasma, it is at present not possible to draw a valid conclusion about the possibility of such a transition.

The difficulties of the theoretical study of the highly nonideal plasma put in the forefront experimental methods of investigation. There are complexities here caused by the necessity for the production of high pressures at considerable temperatures. Moreover, in view of the optical opacity of a highly nonideal plasma and the arbitrariness of the division of the electrons into free and bound electrons[2], it is not possible to measure the plasma parameters by standard methods, and the development of special diagnostic methods is required. Therefore, the number of experimental articles on the thermodynamics of a nonideal plasma of high charged-particle concentration is very limited[7-9].

An effective method for obtaining and investigating a nonideal plasma is the pinching and irreversible heating of cesium vapor in a shock-wave front[10]. The low ionization potential of cesium makes it possible to obtain an appreciable concentration of charged particles n_e at relatively low temperatures T, so that the nonideality parameter $\Gamma = e^2/kTD$ ($D = (kT/8\pi n_e e^2)^{1/2}$) turns out to be substantial, and the large molecular weight of cesium facilitates its heating by the shock wave. The high volatility of cesium allows us to obtain the necessary initial vapor density at relatively low temperatures. At the same time, the optical opacity of the cesium vapor, as well as the shock compression of the plasma, does not permit the use of the well-developed optical diagnostic methods. The equation of state of the nonideal cesium plasma was therefore determined in the present work (in analogy with the dynamical investigation of condensed media[11]) by recording the mechanical quantities of the shock compression. A previously developed[1] technique allowed us to determine the caloric equation of state of the shock-compressed plasma, to find its temperature, and to construct the thermodynamically complete equation of state from the results of the dynamical experiments without introducing restricting assumptions about the properties and nature of the medium under consideration.

2. THE CESIUM PLASMA SHOCK TUBE

To obtain a cesium plasma of high charged-particle concentration, we must create a high-intensity shock wave in high-density cesium vapor[10]. It is for this purpose that the shock tube shown in Fig. 1 was constructed[13]. The shock tube with a low-pressure chamber of length 2.6–3 m and internal diameter of 45 mm was placed in a cylindrical heater (~ 4 m) which allowed thermostatic control of the tube at temperatures

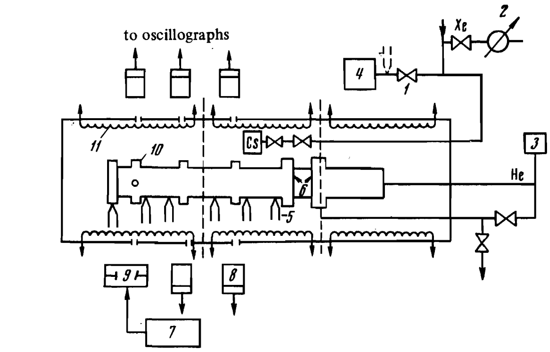

FIG. 1. Diagram of the shock tube: 1) valve; 2) vacuum gauge; 3) compressor; 4) vacuum pumps; 5) thermocouple; 6) diaphragms; 7) pulse radiography system; 8) photomultiplier with cathode follower; 9) x-ray tube; 10) tube window; 11) heating coil.

of up to 700° C. As measuring windows we used synthetic corundum windows soldered in at the rims (for the detection of optical radiation) and 5-mm thick beryllium sleeves through which the x-ray measurements were made. A high-pressure chamber of length 60 cm was realized in a double-diaphragm scheme that obviated the need for a controlled rupture of the diaphragms and for the use of extremely thick membranes. However, even for such a scheme, the thickness of the steel membranes reached 3 mm at pressures of the propelling gas (He) of 600—700 atm. The membranes were sealed with annular stellite knive edges.

To construct the equation of state of the cesium plasma, we measured the initial pressure P_1 and temperature T_1 of the cesium vapor, the velocity u_1 of the shock wave, and the density $\rho_2 = V_2^{-1}$ of the shock-compressed plasma. The pressure P_1 was measured through a buffer gas (Xe) with an accuracy of ±1%; the temperature T_1 was measured with the same accuracy by thermocouples arranged along the tube. The velocity of the front was determined using the basis method (Fig. 2) of recording the radiation of the shock wave with photomultipliers located at three sections of the tube. The characteristic shape of the dense cesium plasma light signal in the form of a narrow radiation peak (Fig. 3) and the large measuring base allowed us to measure the velocity of the wave[1)] with an accuracy of ±1%.

The density ρ_2 of the shock-compressed plasma was measured by a pulse radiography method[14], using the absorption of x-rays of energy 25—29 kV by the plasma. For this purpose a special x-ray apparatus was constructed in which the radiation source was a BSV-9-W tube with up to 1-A current pulses produced by discharging of a capacitor bank unto the tube. The radiation that penetrated the plasma was recorded by an FÉU-12 photomultiplier with an NaI scintillator. The diameter of the x-ray beam was ~ 3 mm in the investigations of the incident shock wave and ~ 1 mm for the reflected shock wave. The exact calibration of the measuring system was carried out under continuous

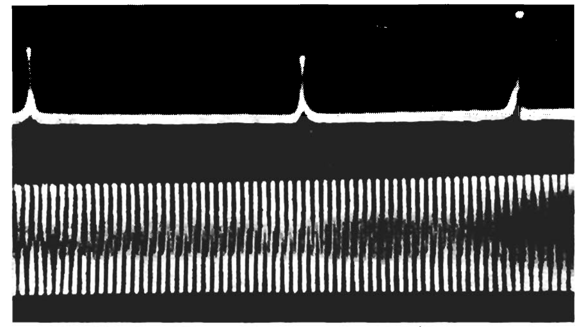

FIG. 2. Shock-wave velocity measurement oscillogram. The quartz frequency was 100 kHz.

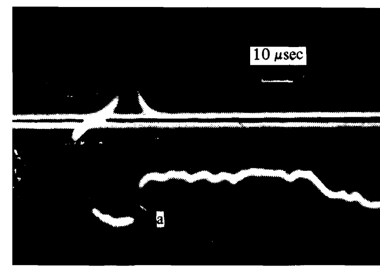

FIG. 3. Top: light signal of shock wave; bottom; x-ray photograph of x-ray absorption; a) shock wave front.

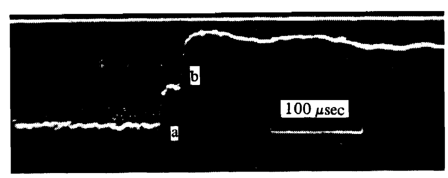

FIG. 4. Oscillogram of x-ray absorption in reflected shock wave: a) incident shock wave; b) reflected wave.

operating conditions of the x-ray tube using xenon. a neighboring element of cesium in the periodic table.[2)] An oscillogram of the x-ray absorption by the plasma behind the incident shock wave front is shown in Fig. 3.

To investigate the reflected shock waves, we inserted a piston in the low-pressure chamber with its face fixed at a distance of 1 cm from the section where the x-ray measurements were made. In this case we can determine from the absorption oscillogram (Fig. 4), besides the density ρ_2 of the plasma behind the incident wave front, also the density ρ_5 behind the reflected wave as well as the velocity u_5 of the reflected shock wave. In view of the small measuring base, the accuracy of the velocity measurement is worse for the reflected wave than for the direct wave and is ±10%. Since shock-compressed vapors are highly superheated with respect to the tube walls, condensation of cesium into the liquid phase is possible behind the shock discontinuity front[13,15]. The x-ray photographs obtained show, however, that this effect is negligible under our conditions and does not result in an anomalous reduction in the size of the cesium plasma mirror[13]. This is possibly due to the presence in a cesium vapor of an extremely small quantity of foreign gases ($\lesssim 0.2\%$), which create a diffusional resistance to the condensation flow of the cesium to the walls of the shock tube.

3. EXPERIMENTAL RESULTS

It follows from the conservation laws in the shock discontinuity[16] that during the propagation of the shock

[1)]Comparison of the oscillograms of the light signal and the x-ray absorption shows that the maximum of the light signal coincides to within 1–2 μsec with the compression shock.

[2)]The calibration curve was plotted with allowance for the difference in the charge numbers of Xe and Cs.

wave through the experimental material the pressure P_2 and the specific enthalpy H_2 behind its front take the form

$$P_2 = P_1 + \rho_1 u_1^2 \left(1 - \frac{\rho_1}{\rho_2}\right), \quad H_2 = H_1 + \frac{u_1^2}{2}\left[1 - \left(\frac{\rho_1}{\rho_2}\right)^2\right]. \qquad (1)$$

Equations (1) allow us to determine in each experiment P_2 and H_2 of the shock-compressed plasma from the prescribed initial states (subscript 1) and from the results of the measurement of the velocity u_1 of the front and the density ρ_2. The values of $\rho_1 = V_1^{-1}$ and H_1 entering into (1) are here computed from the ideal-gas formulas with allowance for the dimerization of the cesium vapor[17]. It follows from the relation (1) that the pressure and enthalpy of the material behind the shock discontinuity in gaseous media (the high degree of compression ρ_2/ρ_1) depend weakly on ρ_2, and are practically determined by only the velocity u_1 of the shock wave and the initial conditions. It is precisely for this reason that the measurement of the density of the shock compression is more suitable in an investigation of the equation of state of gaseous media by dynamical methods.

The experiments were performed under different initial conditions ($P_1 \approx 0.15$–0.5 atm) and with different intensities ($M \approx 5$–7) of the shock waves, and this allowed us to obtain experimental information about the caloric equation of state H = H(P, V) of the plasma in a broad region of the phase diagram. The upper bound of the initial pressures was determined by the necessity for obtaining high-intensity shock waves at high ($T_1 \sim 650°C$) initial temperature; the lower bound, by the necessity for the elimination of radiation losses from the energy balance at the shock wave front[16], as well as by the absence of condensation of cesium on the walls of the shock tube[15]. Some of the experimental results obtained are shown in Table I, where they are compared with the Debye theory in the grand canonical ensemble (DGE).

Let us estimate the expected error in the measurements. Errors $\sim 1\%$ in the measurement of P_1 and $\sim 1\%$ in T_1 yield an error $\sim 2\%$ in ρ_1. The accuracy in the measurement of the velocity u_1 is $\sim 1\%$. To determine the error in the measurement of the density ρ_2, x-ray photographs of the shock waves were taken in xenon in the ranges of u_1, P_1, and T_1 corresponding to the experiments with cesium. The degree of ionization of xenon is in this case small and the states of the shock compression can be computed sufficiently accurately. Comparison of the results of the xenon density measurement with the calculated values shows that the error in the measurement of the density ρ_2 is $\sim \pm 10\%$. This value includes the error in the determination of P_2 and H_2 because of inaccuracy in the measurement of the parameters entering into (1).

Substantially larger nonideality parameters are attained in the plasma produced behind the reflected shock wave front[10]. To determine the thermodynamic parameters of the plasma compressed in the reflected wave (subscript 5), we used the conservation laws:

$$\rho_5 = \rho_2\left[1 + \left(1 - \frac{\rho_1}{\rho_2}\right)\frac{u_1}{u_5}\right],$$

$$P_5 = P_2 + \rho_2\left[\left(1 - \frac{\rho_1}{\rho_2}\right)u_1 + u_5\right]^2 - \rho_5 u_5^2,$$

$$H_5 = H_2 + \frac{1}{2}\left[\left(1 - \frac{\rho_1}{\rho_2}\right)u_1 + u_5\right]^2 - \frac{u_5^2}{2}. \qquad (2)$$

Measurement of the density ρ_5 and the velocity u_5 of the reflected shock wave allows us to determine from (2) the caloric equation of state H = H(P, V) of the plasma behind the shock wave front and, furthermore, to verify the validity of the relation (2), in view of the presence of the "superfluous" measurable parameter. This verification is advisable in view of the complexity of the phenomena which occur during the reflection of the shock wave[18].

The results of the measurements for the reflected shock wave are given in Table II, where they are compared with the Debye theory in the microcanonical (DME) and grand canonical (DGE) ensembles of statistical mechanics. In the case of the reflected shock wave, since the large discontinuity in the density leads to an almost complete absorption of the x-rays, sufficiently reliable x-ray photographs of the shock waves in xenon, which are necessary for the estimation of the errors, are impossible to take. The measured (from x-ray absorption) density ρ_5 is given in Table II together with the computed (from the measured u_5 and the first of the relations (2)) value ρ_5'. The largest discrepancy between these quantities (up to 20%) was considered as the error in the determination of ρ_5.

4. CONSTRUCTION OF THE EQUATION OF STATE FROM THE DYNAMICAL EXPERIMENTS

The set of experimental data obtained allows us to construct the caloric equation of state H = H(P, V) of the shock-compressed plasma in the region of the P-V plane covered by the Hugoniot adiabats (Fig. 5).

Table I. Parameters of the state behind the incident shock

№	Experiment								DGE computations at given P and H					DGE computations at given P and V	
	P_1, atm	T_1, °K	u_1, km/sec	P_2, atm	$H_2\cdot10^{-10}$, erg/g	T_2, °K	$\rho_2\cdot10^3$, g/cm³	$n_2\cdot10^{-19}$, cm⁻³	$\rho_2\cdot10^3$, g/cm³	$n_2\cdot10^{-19}$, cm⁻³	T_2, °K	$n_e\cdot10^{-18}$, cm⁻³	Γ	T_2, °K	$H_2\cdot10^{-10}$, erg/g
1	0.308	935	1.91	18.0	1.94	5850	4.0	1.84	4.07	1.86	5910	3.68	1.44	5990	1.97
2	0.507	915	1.57	20.0	1.33	5300	5.4	2.46	5.57	2.54	5090	2.39	1.45	5500	1.60
3	0.449	925	1.69	20.0	1.53	5350	5.3	2.42	5.31	2.42	5410	3.03	1.50	5580	1.54
4	0.412	940	1.86	22.0	1.84	4650	5.1	2.32	5.17	2.36	5880	4.19	1.56	5970	1.91
5	0.476	924	1.98	29.5	2.05	6750	5.6	2.55	6.37	2.91	6300	6.10	1.70	6800	2.41
6	0.460	932	2.08	30.5	2.23	7150	5.1	2.32	6.16	2.82	6560	6.91	1.69	7400	2.83
7	0.428	889	2.10	31.0	2.28	7050	5.2	2.37	6.14	2.80	6640	7.14	1.69	7330	2.77
8*	0.165	878	1.87	9.75	1.80	5700	2.6	1.19	2.38	1.09	5580	2.08	1.19	5280	1.57
9*	0.350	825	1.53	13.0	1.32	4650	3.9	1.78	3.79	1.76	4990	1.70	1.27	4720	1.25
10*	0.347	910	1.85	19.0	1.82	5700	4.4	2.01	4.52	2.06	5990	3.66	1.48	5920	1.90

*The asterisks indicate experiments in which only the direct shock wave was investigated.

Table II. State of cesium plasma behind the reflected shock wave

№	Experiment					DGE computations				DME computations		
	P_5, atm	$H_5\cdot10^{-10}$, erg/g	$\rho_5\cdot10^2$, g/cm³	$n_5\cdot10^{-20}$, cm⁻³	$\rho_5'\cdot10^2$, g/cm³	$\rho_5\cdot10^2$, g/cm³	$n_5\cdot10^{-20}$, cm⁻³	Γ	T_5, °K	$\rho_5\cdot10^2$, g/cm³	$n_5\cdot10^{-20}$, cm⁻³	T_5, °K
1	156	4.02	1.85	0.845	1.86	1.72	0.78	1,91	10700	1,40	0,640	12800
2	145	2.66	2.59	1.14	2.43	2.40	1.096	2,50	7900	3.04	1.39	9900
3	160	3.10	2.60	1.19	2.49	2.26	1.03	2,41	8850	2.74	1.25	10500
4	192	3.76	2.20	1.005	2.42	2.18	0.995	2,19	10300	2.22	1.015	11900
5	233	4.35	2.39	1.09	2,25	2,25	1,03	1.97	11800	2.20	1.005	13200
6	243	4.72	1.90	0.868	2.10	2.12	0.968	1.79	12700	2.10	0.960	14000
7	250	4.84	2.20	1.005	2.17	2.06	0.940	1.74	13000	2.05	0.935	14500

Enthalpy, however, is not a thermodynamic potential with respect to the PV variables, and to construct the complete thermodynamics of the system, we must find, besides H = H(P, V), the supplementary temperature function T = T(P, V)[19]. As has been noted, a direct measurement of the plasma temperature T together with the other parameters of the shock compression is not possible under our conditions, in view of the optical opacity of the plasma and the cesium vapor ahead of the shock wave front. This does not allow the application of the well-developed optical methods of plasma diagnostics to such a medium. Comparison of the oscillograms of the radiation emitted by the cesium plasma ($T_2 \sim 7 \times 10^{3\circ}$K) with the radiation emitted by the shock wave in the "cold" ($T_2 \sim 2 \times 10^{3\circ}$K) xenon shows (Fig. 6) that the radiation nucleus is practically completely screened by the boundary layer[13].

The temperature of the shock-compressed cesium plasma was determined using a previously developed[12] thermodynamic technique. The equilibrium temperature T(P, V) is related to the experimentally known caloric equation of state H = H(P, V) by a differential equation which follows from the second law of thermodynamics[20]:

$$\left(\frac{\partial H}{\partial V}\right)_P \frac{\partial T}{\partial P} - \left[\left(\frac{\partial H}{\partial P}\right)_V - V\right]\frac{\partial T}{\partial V} = T, \tag{3}$$

and which was solved by the method of characteristic equations:

$$\frac{dP}{dV} = -\frac{(\partial H/\partial V)_P}{(\partial H/\partial P)_V - V} = f_1, \tag{4}$$

$$\frac{dT}{dV} = -\frac{T}{(\partial H/\partial P)_V - V} = f_2. \tag{5}$$

The characteristic equation (4) defines the isentrope in the P-V plane, while Eq. (5) determines the temperature along this curve. The system of ordinary differential equations (4) and (5) was integrated on an electronic digital computer by the Adams numerical method. The caloric equation of state H = H(P, V), which was necessary for the computation of the functions f_1 and f_2 of the system (4) and (5), was constructed from the experimental data obtained for the direct shock wave in the form

$$H^q(P, V) = \sum_{k+l\leq q}\sum' h_{kl} V^k P^l, \tag{6}$$

where the coefficients h_{kl} were computer-calculated by the Chebyshev orthogonal polynomial method[12]. A statistical analysis with the use of the Fisher criterion[21] showed that it was sufficient for the description of the available experimental data to choose q = 3 in (6). The initial data for the system (4) and (5), T

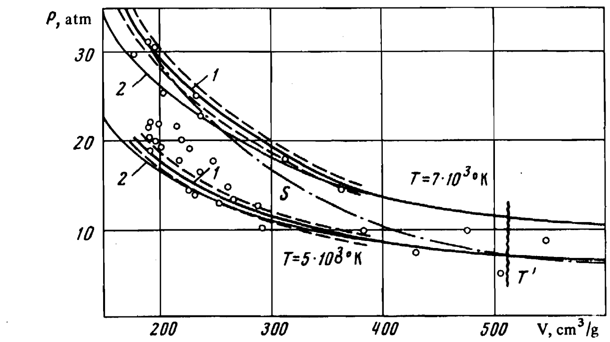

FIG. 5. Cesium plasma isotherms: 1) constructed from (4)–(6); the dashed curves mark off the error region; 2) from the ideal-gas approximation. The points are experimental, S is an isentrope, and the wavy line indicates the region in which the initial data for (4)–(6) were assigned.

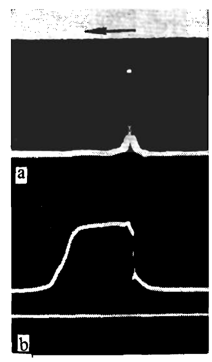

FIG. 6. Radiation emitted by a) cesium and b) xenon behind the shock wave front. The arrow indicates the direction of the time sweep.

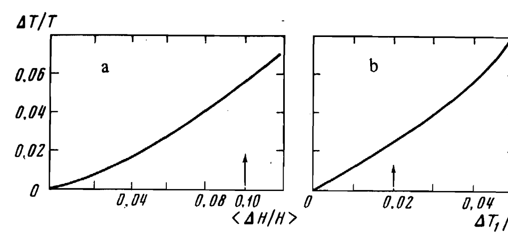

FIG. 7. Dependence of the temperature computation error ΔT/T on: a) the mean experimental error ⟨ΔH/H⟩; b) the error ΔT′/T′ in the initial data.

T′ = T′(P), were prescribed in the region of the parameters (the wavy line in Fig. 5) where the nonideality is slight, and the methods used to compute the equations of state[22] yield results which are reliable and agree with experiment.

An estimate of the accuracy of the temperature determined in this way was made by means of the Monte-Carlo method through computer simulation of the probability structure of the measurement process[12]. Figure 7a shows the dependence of the temperature-computation error ΔT/T for one of the experimental points on the mean experimental error ⟨ΔH/H⟩. The dependence of the error ΔT/T on the error ΔT′/T′ in the initial data is shown in Fig. 7b. One hundred realizations of an ensemble of random points were used for constructing these curves[12]. The arrows in Fig. 7 indicate the expected errors in ⟨ΔH/H⟩ and ΔT′/T′. A special check demonstrated that the solution $\tilde{T}(V)$ of the characteristic

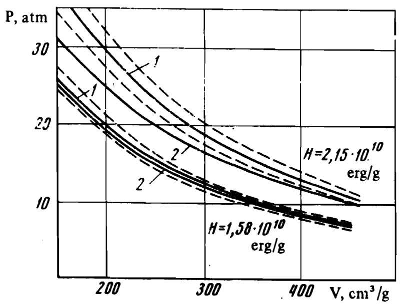

FIG. 8. Curves of constant enthalpy of cesium plasma. The designations are the same as in Fig. 5.

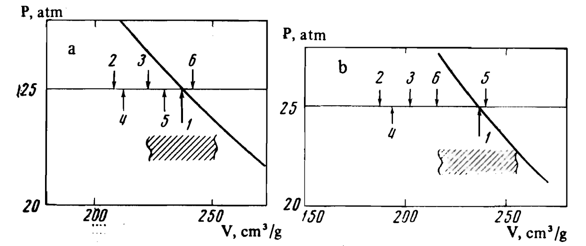

FIG. 9. State in the incident shock wave. Comparison of experimental isotherm (a) ($T = 7 \times 10^3$ °K) and of constant-enthalpy curve (b) ($H = 2.23 \times 10^{10}$ erg/g) with theoretical computations: 1) experimental result; 2) DME theory; 3) DGE theory; 4) DME theory ($Q_{Cs} = 2$); 5) "ideal" gas ($Q_{Cs} = 2$); 6) DGE theory ($Q_{Cs} = 2$). The error band is shaded.

system (4) and (5) has a normal distribution if the experimental-error distribution is normal. On the basis of the computations it can be concluded that the error in the determination of the temperature at the experimental points is roughly 8%.

Figure 5 shows the isotherms of a nonideal cesium plasma computed from Eqs. (4) and (6); the dashed curves in the figure indicate the error region obtained for each isotherm by the Monte Carlo method. Since there exists between the states in the direct and reflected shock waves a phase-diagram region for which experimental data are not available, the temperature for the reflected shock wave was not computed.

5. DISCUSSION OF THE RESULTS

The experimentally recorded states of the cesium plasma are compared in Table I with the results of computations performed with the Debye theory in the grand canonical ensemble[3] (DGE)[23]. The theoretical values of the parameters were computed from the experimental P_2 and H_2, and the comparison in this case is between the theoretical and experimental values of ρ_2 and T_2. Furthermore, the values of T_2 and H_2 computed from the experimental P_2 and V_2 are given in Table I. It can be seen that the experimental value for the density in the first case, and for the enthalpy in the second case, are smaller than the theoretical values. Comparison of the "experimental" isotherms in Fig. 5, as well as of the states of Table I, with those computed in the ideal-gas approximation shows that the pressure of a nonideal, partially ionized plasma is higher than the ideal-gas value, an effect theoretically discovered earlier in[22]. The constant-enthalpy curves (Fig. 8) constructed directly from the experimental points behave in the same way. The reason for such an overestimate of the isotherms is that in a nonideal, partially ionized plasma the interaction between the particles leads to an increase in the number of free charges, which increase the kinetic part of the pressure (and enthalpy) in such a way that this increase exceeds the reduction in pressure due to polarization. The tendency for the pressure to be higher than expected obtains for all the curves constructed in Figs. 5 and 8, but with increasing temperature (enthalpy) this tendency manifests itself more and more sharply, so that for $T_2 = 7000$°K and $H_2 = 2.15 \times 10^{10}$ erg/g the curves lie outside the limits of the expected errors. These curves are compared with the theoretical curves in Fig. 9 for the incident shock wave and in Fig. 10 for the reflected.

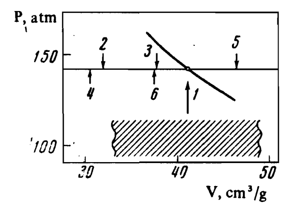

FIG. 10. State in the reflected shock wave. The error band is shaded. The designations are the same as in Fig. 9; $H = 2.66 \times 10^{10}$ erg/g.

It can be seen from Fig. 9 that the overestimates of the curves T = const and H = const given by the self-consistent[22] theories are not high enough and do not agree with the experimental results. Although we can describe the experimental isotherm by postulating an additional reduction of the ionization potential in the Saha equation and appropriate corrections in the equation of state, such a procedure leads to a still larger discrepancy for the H = const curves. Agreement can be attained within the framework of existing concepts only by a drastic reduction of the contribution of the bound states (Q_{Cs}) and only for those theories in which corrections for the interaction of free charges are considerably less than the Debye corrections computed in the microcanonical ensemble of statistical mechanics[22] (DME). This is illustrated by the limiting cases shown in Fig. 9, namely, by the ideal-gas and Debye (DGE and DME) approximations, in which only the principal energy state ($Q_{Cs} = 2$) is taken into account[4].

The experimental results apparently point to the fact that the Debye (DME) theory and the theories close to it[2,22] overestimate the corrections to the thermodynamic functions for the interaction in the continuous spectrum. At the same time the effect of the nonideality on the contribution of the bound states is substantial. Since there is at present no plasma theory applicable to any degree of nonideality, we can only speak of extrapolated properties of one theory or another in the highly nonideal region of the parameters. In this sense the states behind the front of the direct and reflected waves can be described by the theories which give corrections for nonideality not exceeding the corrections of the Debye theory in the grand canonical ensemble (DGE).

[3] This theory yields a somewhat smaller disagreement with experiment than other consistent theories [22].

[4] At the temperatures under consideration this corresponds to limiting the partition function Q_{Cs} at the energy level ~2 eV.

One of the most interesting characteristics of the behavior of a plasma under strong-nonideality conditions is the supposed possibility of stratification of the system into two phases with different physical properties, a transition which is connected with the loss of thermodynamic stability by a number of model equations of state[2]. The effects of thermodynamic instability in a cesium plasma should in that case manifest themselves at relatively low values of the parameters[2]. In dynamic experiments with condensed media the existence of phase transitions is detected by finding kinks in the Hugoniot adiabat at the phase boundary. In the present experiments such a possibility of detecting the phase transitions is out of the question in view of the purely technical difficulties involved in maintaining from experiment to experiment strictly the same prescribed initial conditions P_1 and T_1, so that each of the experimental points obtained corresponds to its own adiabatic curve. For the detection of the phase transitions (under the assumption of thermodynamic equilibrium behind the shock wave front), we can use the isentropes and isotherms constructed by integrating (4) and (5) with the entire set of experimental data used to compute (6). The absence of kinks in the isentropes and isotherms in the P-V plane indicates the absence in the investigated parameter range of plasma condensation with appreciable heat of transition and volume jump.

Furthermore, no hydrodynamic anomalies of the type of a double-wave structural formation were discovered in the present experiments, although it is doubtful whether the phenomenon in question could occur in a cesium plasma[3]. Moreover, the nature of the corrections to the thermodynamic functions of a nonideal plasma, which has been deduced on the basis of the experimental results, makes unlikely the possibility of a phase transition in the investigated region of the parameters.

We are deeply grateful to V. M. Ievlev and K. I. Artamonov for their constant attention and support of the investigations, and to I. L. Iosilevskiĭ, Yu. G. Krasnikov, A. N. Starostin and G. É. Norman for numerous useful discussions.

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Translated by A. K. Agyei
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