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INVESTIGATION OF LANDAU-DAMPING EFFECTS ON SHOCK FORMATION

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Landau damping in plasmas of equal ion and electron temperatures (alkali plasmas) may prevent the formation of a shock. Shocks are produced when the ratio T_e/T_i is increased to about 8 or so by cooling the ions through i-n collisions.

We report in this note preliminary results concerning the formation of steep wave fronts (shocks) in a Q device.[1] A schematic view of the experimental arrangement is shown in Fig. 1(a). The plasma is produced by surface ionization of cesium atoms on a hot (~2500°K) tantalum plate, and is confined radially by a uniform and constant magnetic field of intensity up to 10 000 G. The plasma column, about 1 m long, is terminated at the opposite end from the generating plate by a second tantalum plate, which can either be heated up to ~2500°K or left at room temperature. A grid is inserted at 30 cm from the generating plate, the plane of the grid being normal to the $\vec{B}$ lines. The grid consists of tungsten wires 2.5×10^{-3} cm in diameter, spaced 3×10^{-2} cm. It is normally biased at −20 V with respect to the generating plate, and it absorbs most of the ions from the plate, thereby producing a plasma density distribution along the axis as indicated in Fig. 1(b). By suddenly varying the grid bias to approximately −2 V, the grid is "open," i.e., its transmission to the plasma is strongly enhanced. Our measurements indicate that the voltage pulse on the grid may vary its transmission from ~10 to ~80%. A similar technique has already been used[2] to study the propagation and damping of ion-acoustic waves in the cesium plasma of a Q device. In the work of Ref. 2, however, the density modulation by the grid amounted only to a few percent of its dc value and was sinusoidal in time. In our present arrangement the "opening" of the grid is somewhat the equivalent of the breaking of the diaphragm in a conventional shock tube. It should be noticed, however that (a) our experiments are performed in alkali plasmas produced in a manner entirely independent of the presence of a shock, and (b) the ion and the electron temperatures, T_i and T_e, are approximately equal (~2500°K) if the pressure of the neutral gas in the device is kept sufficiently low ($p \lesssim 10^{-4}$ mm Hg). At higher neutral gas pressures one may cool the plasma ions to about room temperature while keeping T_e near 2500°K, thereby achieving values of T_e/T_i as large as 8 or so.

In a first series of experiments we have investigated, by means of Langmuir probes movable along the plasma column, the propagation

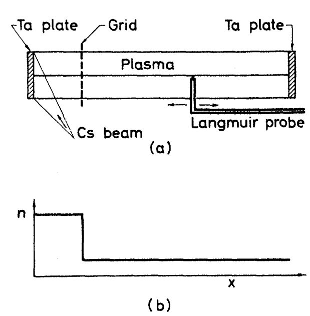

FIG. 1. (a) Schematic diagram of the experimental arrangement, and (b) density distribution along the plasma column before "opening" of the grid.

of the plasma pulse produced by the sudden "opening" of the grid, always keeping the neutral gas pressure below 10^{-5} mm Hg. At these neutral pressures the condition $T_i \simeq T_e$ prevails. The plasma density was kept in the range 10^{10} to $\sim 5\times 10^{11}$ cm^{-3}. In these conditions, we have consistently observed a "spreading out" of the pulse traveling away from the grid, i.e., no clear indication of a steepening-up of its leading edge. This point is illustrated in Fig. 2, where curves are shown of n vs x, the distance from the grid along the $\vec{B}$ lines, with time after "opening" of the grid as a parameter. At all densities in the range 10^{10} to 5×10^{11} cm^{-3} we have observed the same behavior of the plasma pulse, the rate of spreading being apparently independent of the plasma density. This fact suggests that spreading of the pulse is brought about not through collisional effects, which should be density dependent, but by a collisionless mechanism. A "fluid" picture, even when accounting for the viscosity of the ions through a viscous term as given, for instance, by Braginski,[3] does not appear to account for our observations. On the other hand, a wave-particle interaction mechanism (Landau damping) has the necessary features to agree with our findings.

At this stage, we shall not attempt to compare our results with the available theoretical information on nonlinear Landau damping. We present instead some experimental evidence indicating that, for $T_e \simeq T_i$, it is Landau damping which subtracts energy from the plasma pulse, thereby preventing the formation of a shock. It is known[4] that linear Landau damping of ion-acoustic waves is strongly reduced if the ratio T_e/T_i is made much larger than unity (say 10, or so). We have accomplished the cooling of the plasma ions through i-n collisions, by inserting in the plasma volume a sufficiently large amount of neutral gas (He, Ar, or N_2). This technique, as far as Q devices are concerned, has already been demonstrated[5] and studied in some detail. In the present experiment the actual cooling of the ions is also demonstrated experimentally by recording, at a fixed location in the plasma column, the time of arrival of the plasma pulse as a function of the neutral gas pressure. Typically, at neutral gas pressures p of the order of 10^{-4} to 10^{-3} mm Hg, when ion cooling is expected to begin, the plasma pulse starts being delayed, the delay increasing (up to some limiting value) with increasing p. An additional check is obtained by comparing, for instance, the experimental results obtained with He and N_2 as the neutral gas. We find that the pressures at which the pulse begins being delayed are, in the two cases, in approximately the ratio m_{N_2}/m_{He}.

Ion cooling being achieved, with T_e still close to 2500°K, elimination of Landau damping should allow the formation of a steep leading edge (shock) of the plasma pulse. We have very clearly observed a steepening effect in all cases so far investigated. It has been possible to follow in detail the process of "sharpening up" of the leading edge of the plasma pulse as it proceeds along the column [Fig. 3(a)]. We have

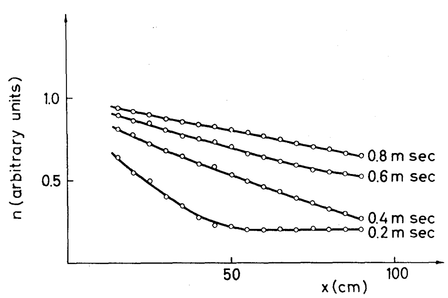

FIG. 2. The plasma density n vs x, the distance from the grid along the axis of the column, at several times after "opening" of the grid ($B = 10\,000$ G; $n \approx 10^{11}$ cm^{-3}; $p \approx 10^{-5}$ mm Hg).

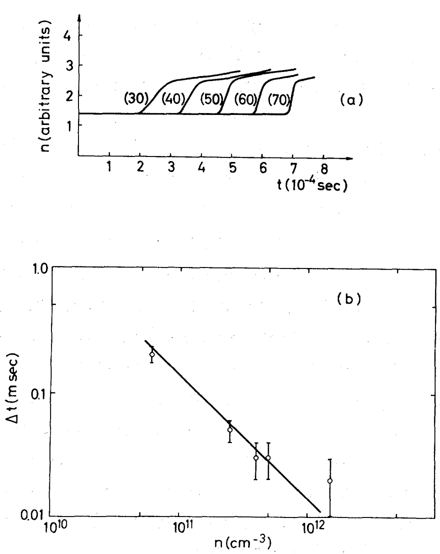

FIG. 3. (a) n vs t (from oscilloscope traces) for x = 30, 40, 50, 60, and 70 cm. [$n \approx 10^{12}$ cm^{-3}; $B = 10\,000$ G; $p(A) \simeq 5\times 10^{-4}$ mm Hg]. (b) The shock thickness Δt at $x = 60$ cm as a function of the plasma density ahead of the shock [$B = 10\,000$ G; p(He) $= 10^{-2}$ mm Hg].

also measured the (limiting) thickness of the shock as a function of plasma density. At pressures $p \simeq 10^{-2}$ mm Hg, with $\lambda_{ii} < l < \lambda_{in}$, l being the thickness of the shock and λ_{ii} and λ_{in} the i-i and i-n collision mean free paths, respectively, we expect l to be determined entirely by λ_{ii}, i.e., $l \sim 1/n$. That this is the case can be seen from the data of Fig. 3(b), where l is shown as a function of the plasma density n ahead of the shock for a He gas pressure of $\sim 10^{-2}$ mm Hg.

In conclusion, our results indicate that in plasmas of comparable ion and electron temperatures Landau damping prevents the formation of a shock wave by overcoming the sharpening effect of the nonlinearities. Landau damping can, however, be "switched-off" by increasing T_e/T_i from unity to about 10 or so. Further details on our measurements will be presented at a later date.

Finally, it should be noted that our results may be relevant to shock formation in interplanetary plasmas.

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ORTHOBARIC DENSITY OF ^{3}He IN THE CRITICAL REGION

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The coexistence curve of ^{3}He has been measured by a dielectric constant technique in the neighborhood of the critical point. The parameters in the relation $|(\rho-\rho_c)/\rho_c| = A[(T_c-T)/T_c]^\beta$ are found to be $\rho_c = 0.04134$ g/cm^3, $T_c = 3.3095$°K, $A = 1.323$, and $\beta = 0.362$. Our value of T_c is some 14 mdeg lower than previous measurements indicate, and our value of β more nearly in agreement with values characteristic of other fluids than was previously found.

The coexistence curve of a fluid near the liquid-vapor critical point can be described by a relation of the form

$$\left|\frac{\rho-\rho_c}{\rho_c}\right| = A\left(\frac{T_c-T}{T_c}\right)^\beta, \tag{1}$$

where ρ_c is the critical density and T_c the critical temperature.[1] Recently, there has been considerable interest in determining the parameters in this relation with improved precision.[2] For "ordinary" fluids such as xenon[3] and carbon dioxide,[4] β is found to be close to $\frac{1}{3}$; however, for the light elements ^{4}He, ^{3}He, and H_2, larger values have been reported.[5-7] This observation prompted the suggestion[8-10] that the value of β might be affected by quantum deviations from the law of corresponding states. Recent work by Roach and Douglass[11] casts doubt on this suggestion. They find that for ^{4}He, $\beta = 0.352 \pm 0.003$, which is to be compared with an earlier estimate[9] of 0.46. Such quantum deviations, if present, should be largest of all for ^{3}He. We have accordingly measured its coexistence curve by means of a dielectric constant technique, using an improved version of an apparatus previously described,[12] and find $\beta = 0.362 \pm 0.001$. Any such deviations are therefore substantially smaller than earlier data suggested. We also find that T_c is some 14 mdeg lower than previously reported. This correction is largely responsible for our smaller value of β, since far from the critical point our data agree well with the results of others.[6,13]