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14. Abstract/Notes

This work describes the observation and modelling of the density rarefaction and subsequent compression associated with a single negative voltage pulse on a spherical electrode.

15. Remarks

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OBSERVATIONS OF AN ION ACOUSTIC OSCILLATION NEAR A PULSED SHEATH

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Abstract: This work describes the observation and modelling of the density rarefaction and subsequent compression associated with a single negative voltage pulse on a spherical electrode.

1. Introduction

The ion acoustic wave is an oscillatory, propagating disturbance in a fluid which comprises positive ions and electrons. At low frequencies ($\omega \ll \omega_{pi}$), the disturbance is quasineutral and the speed of propagation (c_s) is determined by the ion inertia (M) with the electron thermal energy (κT): $c_s = \sqrt{(\kappa T/M)}$.

An isolated spherical electrode immersed in a plasma will usually charge up negatively as the more mobile electrons reach it first. Subsequently, an ion space charge layer or sheath forms around the electrode. Superimposing a negative voltage pulse onto the floating potential causes the ion-rich sheath to expand. If the expansion proceeds at a speed less than the 'acoustic' speed (which is characteristic of the ion fluid) then it is preceeded by a rarefactive disturbance[1-5], which carries into the plasma information about the changing of the sheath dimension. For spherical geometry, it has been predicted[4,5] that a single pulse (e.g. a half cycle of a negative sine wave) would give rise not only to a rarefaction but also to a compressive disturbance, following behind.

2. Experiments

The experiments were carried out in a multi-magnetic-dipole discharge plasma device, similar to that used by other workers[6,7]. The experimental argon plasma had a density of about $10^{15}\ m^{-3}$ (argon pressure 2×10^{-4} mbar), and an effective electron temperature[6] of 2 eV. The working volume of plasma was virtually drift free.

Perturbations in the plasma were created by means of a spherical copper electrode (diameter 0.01m) placed near the mid-plane of the plasma volume. The electrode was supported by (but isolated from) an earthed steel tube although within the discharge region glass sleeving was used around the probe support. Electrical connection to the sphere was by means of an insulated molybdenum wire passing up the axis of the support tube. A moveable, plane Langmuir probe (0.005m diameter molybdenum disk, 'facing' the sphere) was used to monitor the local electron density.

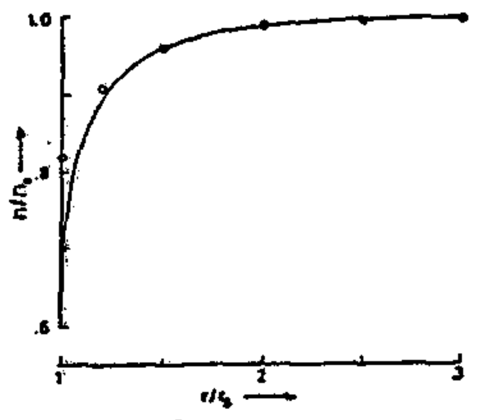


Figure 1. The steady perturbation in quasineutral number density around a spherical electrode. Solid line: theory; open circles: experiment, taking r_s to be 0.01m; c.f. also figs 3 and 5 at t=0.

With the spherical electrode placed in the experimental region, there was a steady perturbation of the plasma as the electrode provided a loss surface. This d.c. perturbation was investigated with the probe biassed a few volts into electron saturation (current propotional to electron density). The results are recorded in fig 1.

A 64 volt negative voltage pulse rising in 5μsec and falling with a similar time constant was applied through a d.c. blocking capacitor to the floating spherical electrode('emitter'). The pulse was repeated every millisecond, allowing the plasma time to recover between pulses, but fast enough for box-car signal averaging techniques to be employed.

(i) a.c. time scan : The a.c. component of the probe current as a function of time was sampled and averaged for several fixed probe-emitter separations. This gives a measure of the density fluctuation as a function of time at different points in space; see fig 2. Rarefactive and compressive features are evident.

(ii) d.c. space scan -: By 'single point mode' averaging the d.c. coupled probe signal as the probe-emitter speration was scanned, the spatial variation of density was recorded for several fixed delays after the start of the pulse; see fig 3. The 'wave' appears superimposed on the presheath.

3. Theory

The model plasma has thermal electrons, temperature T, but cold ions and is taken to be collisionless, ionization-free and quasineutral (with local density n). The electron number density is assumed to follow a Boltzmann relation with potential so that:

$$n=n_0\exp(e\Phi/\kappa T), \quad (1)$$

n_0 being the plasma density where the potential Φ is zero; i.e. remote from any surfaces. The geometry is spherical and symmetrical giving one space dimension, radius, r. The ion behaviour is described by a momentum equation:

$$\partial v/\partial t + v.\partial v/\partial r = -(e/M)d\Phi/dr \quad (2)$$

in which v is the radial ion velocity, and a continuity eqation:

$$\partial n/\partial t + \partial(n.v)/\partial r + 2nv/r = 0. \quad (3)$$

Only quasineutral plasma is modelled here but a well defined space-charge sheath is assumed to exist at the surface of any electrodes; the sheath itself is not included. The assumption of quasineutrality is valid in the vicinity of a sheath provided the scale length of the potential gradient in the pre-sheath region is many Debye lengths ($L \gg \lambda_D$); c.f. the Poisson equation. In the experiments here, this condition is satisfied ($\lambda_D \approx 0.3$mm and $L \approx 10$mm). From fig 1 the extent of the sheath around the sphere can be estimated; the presheath density gradient is also evident. A simple theoretical model for this d.c. presheath is provided the time independent solution[8] of equations (1)-(3):

$$(r/r_s)^2 =[(n/n_0)/\surd\{2e\ln(n/n_0)\}],$$

where r_s is the sheath radius. A value for r_s can be obtained by fitting the formula to the measured variation; see fig 1.

The complete time dependent solution of equations (1)-(3) can be obtained by the method of characteristics[4,5]; details are not given here. The boundaries of the (r,t) solution space are determined by the ion drift velocity in the presheath and by the position of the sheath edge as a function of time. This work aims to identify the sheath edge motion with the plasma disturbance but in the experiments it is not possible to measure the sheath position precisely enough to use this data as input to the theory. The experiment controls the voltage waveform applied to the launching electrode. The current to the electrode is closely related to the sheath motion[5], but it was not within the scope of the experiments to determine this quantity. In the next section, the experimental results are compared with characteristics calculations which have assumed a sheath edge motion with a rise time and 'periodicity' similar to the applied voltage.

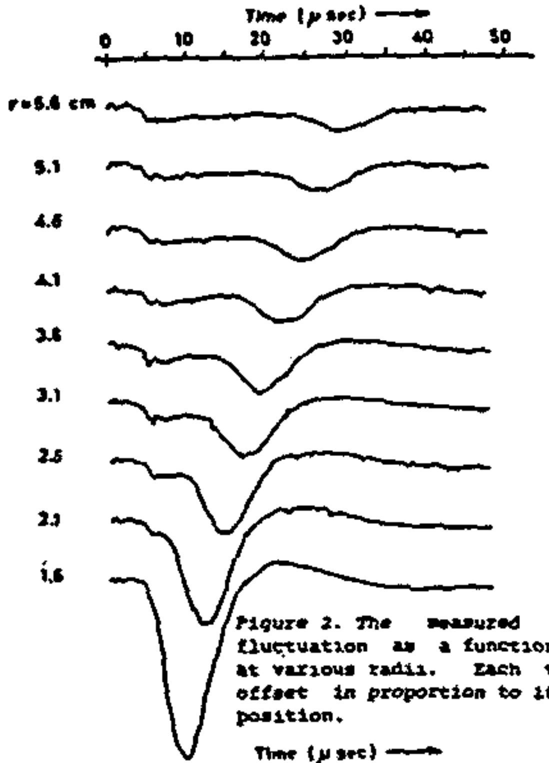


Figure 2. The measured density fluctuation as a function of time at various radii. Each trace is offset in proportion to its radial position.

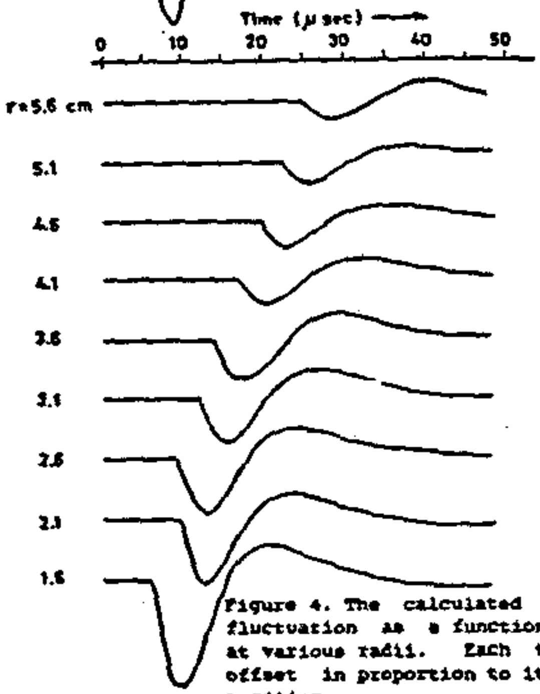


Figure 4. The calculated density fluctuation as a function of time at various radii. Each trace is offset in proportion to its radial position.

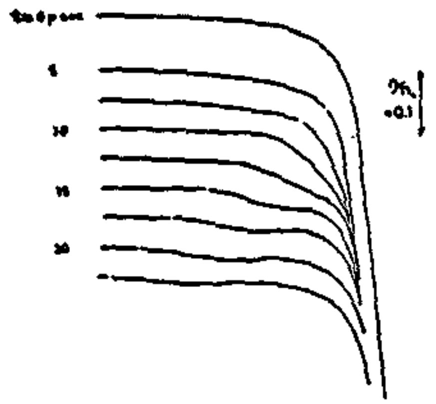


Figure 3. The measured total density as a function of radius for several different delays after the start of the pulse.

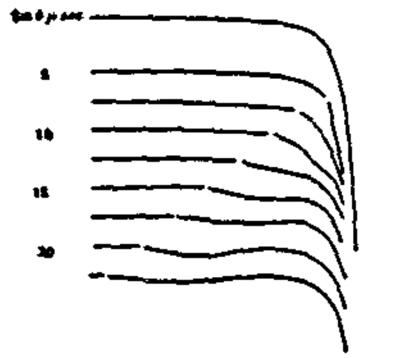
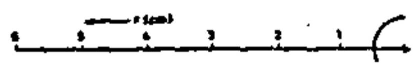


Figure 5. The calculated total density as a function of radius for several different delays after the start of the pulse.



4. Results

Figures 4 and 5 show computed density variations equivalent to the observations recorded in figures 2 and 3 respectively. The time and distance scales have been fitted by taking the initial sheath radius deduced in section 3.6 and the ion acoustic speed measured from the experimental data. The sheath edge motion must also be prescribed and was chosen to be:

$$r = r_s[1 + 0.3(c_s t/r_s)^2 \exp(-c_s t/0.6 r_s)].$$

The rise time is consistent with that of the applied voltage pulse. Increasing the amplitude of this motion increases the amplitude of the density fluctuations at all radii and for all times. Changing the rise and fall times directly adjusts the rise and fall of the density fluctuations.

Comparing the appropriate figures shows there to be good agreement between the calculations and the observations. The largest difference appears to be in the amplitude of the pulse close to the electrode (e.g. $r = 1.6$cm in fig 2). This may be due to ionization in the region of the emitter [8].

The close agreement between the observed (points) and theoretical (solid line) progress of the rarefaction front with time is shown in fig 6. Note that the rarefaction accelerates away from the sheath edge (r=1cm) where the incident ion flow is virtually sonic.

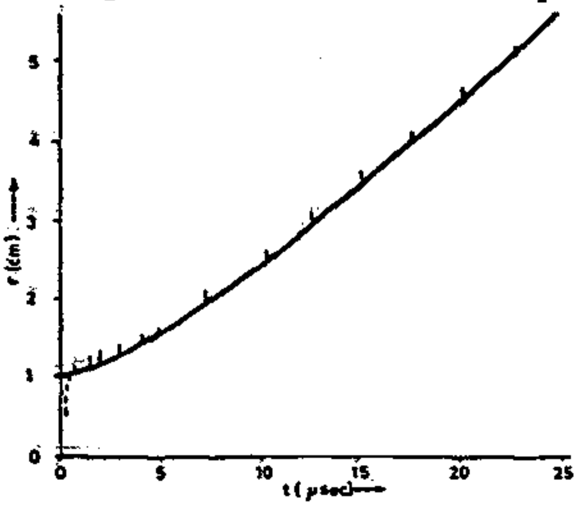


Figure 6. The position of the rarefaction front as a function of time; solid line theory. (Sheath radius approximately 0.01m).

This work has described the launching of a rarefactive and a compressive disturbance from a single pulse on a spherical emitter. A theoretical model which agrees well with the observations also locates the sheath edge as the source of the perturbations.

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OBSERVAÇÕES E NOTAS

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APÓS A PUBLICAÇÃO, ESTA FICHA SERÁ ARQUIVADA JUNTAMENTE COM A VERSÃO ORIGINAL