Pramāṇa, Vol. 15, No. 6, December 1980, pp. 525–530. © Printed in India.

Fake double layers in double plasma devices

S K MATTOO, Y C SAXENA, A N SEKAR
Physical Research Laboratory, Ahmedabad 380 009, India

MS received 11 August 1980

Abstract. The double layer like potential jumps have been observed in a double plasma device. They do not correspond to a switching of plasma potential from one metastable state to another but are caused by the ionisation of a very minute amount of the gas that inevitably leaks into the system during the probe movement.

Keywords. Double layer; double plasma device; ionisation.

1. Introduction

A double layer is a sharp discontinuity in plasma potential which results in electric fields that may accelerate charged particles to energies above the thermal energy. A widespread interest in the study of these layers has been stimulated by several recent experimental (Torvén 1965; Andersson *et al* 1969; Lutsenko *et al* 1975; Quon and Wong 1976; Hudson and Mozer 1978; Coakley *et al* 1978; Levine *et al* 1978; Leung *et al* 1980) and theoretical (Block 1972; Montgomery and Joyce 1969; Goertz and Joyce 1975; Knorr and Goertz 1974; Smith and Goertz 1978; DeGroot *et al* 1977; Singh 1979, 1980) studies dealing with their formation and stability. Most of these investigations have been summarised in review articles (Block 1972; Shawhan *et al* 1978; Raadu and Carlqvist 1979; Torvén 1979).

Double layers have been detected in numerous laboratory experiments. Detailed measurements of the structure of these layers can however be obtained only in the experiments at low plasma densities. Quon and Wong (1976) claim to have produced double layers at low plasma densities ($n \sim 10^{14}\ m^{-3}$) in a filament discharge-type double-plasma device. However, Coakley and Hershkowitz (1979) detected strong double layers in their triple-plasma device but were unable to produce them in their double-plasma device. This has lead to a controversy whether or not double layers can be produced in double-plasma devices. Although they were unable to achieve double layers in their double-plasma device, they could produce what they have called pseudo-double layers. It was found that as the axial position of a monitoring probe was changed in the target chamber, a point was reached at which the potential of the entire plasma changed. This observation has been attributed to the fact that the plasma in the target region of the double plasma device possesses two metastable states.

Although all our attempts so far have failed to produce a strong and stable double layer in the double plasma device, we have obtained results which can explain the observations of pseudo-double layers (Coakley and Hershkowitz 1979). These results are reported in the following.

2. Experimental system

The experimental arrangement is shown in figure 1. It is a double-plasma device consisting of two chambers electrically insulated from each other. The two chambers are separated by two closely spaced grids G1 and G2 . Another grid G3 is provided at the end of the target chamber.

The whole system is pumped to a base pressure of 10^{-5} torr. The system is operated with argon at neutral pressures ranging between 5×10^{-5} to 3×10^{-4} torr. Plasma in the the source chamber is produced by bombardment of neutral gas with 60 eV electrons emitted from 24, 8 cm long tungsten filaments placed at one end of the chamber. Plasma in the target chamber is due to plasma flow from the source chamber. The plasma density in the target region is typically $n\sim10^{14}$ m^{-3} and electron temperature is $\sim$2 eV.

In the normal mode of operation grid G1 is biased 0 Vwith respect to the source and G2, 0–10 V with respect to the target. The plasma potentials can be varied by applying an appropriate voltage bias between the two chambers to produce plasma flows. Grid G3 is provided so as to reflect at its sheath the low energy electrons and thus act as a virtual source for trapped electrons that are required for the formation of a double layer. The walls of the target chamber are grounded.

Diagnostics consists of a two-sided collecting Langmuir probes, emissive probes and energy analyzers. Plasma potential is measured by the emissive probe and electron and ion energy distribution functions are obtained by collecting Langmuir probes and energy analyser. The probe-shafts are insulated from the plasma.

3. Results and discussions

By varying the relative bias between the source and target chambers, a large electron current can be made to flow from the source to the target chamber. The space-charge

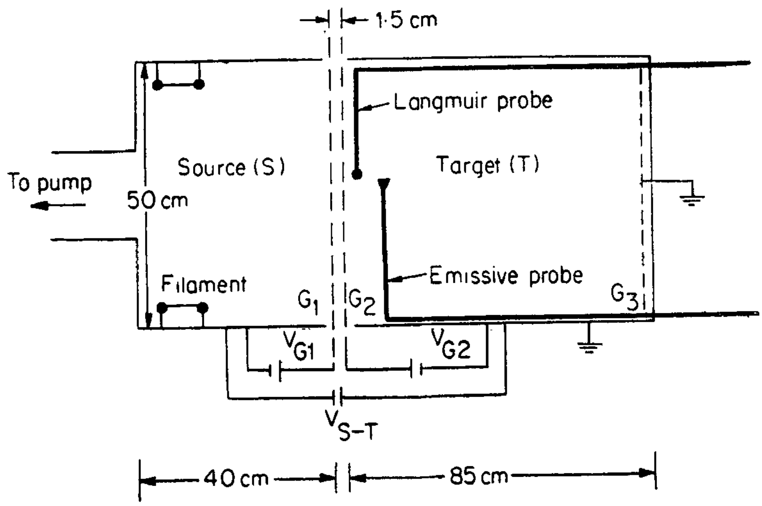

Figure 1. Schematics of the double plasma device. Drifting electrons are produced by biasing the source chamber negative with respect to the target chamber. Grid Gl is biased 0 V with respect to the source, potential of the grid G2 is varied between 0–20 V with respect to the ground, and G3 is grounded.

effect of this current is to lower the plasma potential in the target plasma region close to the grid G2 and the plasma potential is negative with respect to the ground. The pressure of argon neutral gas is carefully adjusted so as to prevent complete neutralisation of the space charge of the electron current.

In a certain range of neutral gas pressures, below a critical pressure, plasma potential changes $\triangle\phi \gtrsim kT_e/e$ extending over several tens of Debye lengths, are observed. These extended potential structures are being investigated and do not form the subject matter of the present paper. At a critical neutral gas pressure, determined by relative biases on grids and between target and source chambers, the plasma potential undergoes a very sudden (over distances ~Debye length) transition as the position of the emissive probe is changed in the target region. Figure 2 illustrates the observations of such sharp potential jump in one typical case.

The profile A is obtained while the emissive probe is moved away from the grid G2. It can be seen that at a certain position in the target chamber the plasma potential makes a sharp transition from a low-state of −6 V to a high-state of +4·4 V in a distance of $\lesssim$0·2 cm. At this instance, there occurs a visible increase in the plasma glow indicating that the plasma density has increased. Also collecting Langmuir probe shows that the plasma density increases from $2{\cdot}4\times 10^{14}$ m^{-3} to 4×10^{14} m^{-3}. From the analysis of Langmuir probe trace we do not find any indication for the presence of beam electrons with energies less than or equal to the potential jump. The profile B corresponds to the measurements obtained while the emissive probe is moved from the region of high-potential state towards the grid G2 immediately after profile A is obtained. In this profile a transition to low-potential occurs at a position closer to the grid G2 and different from the position of transition in the profile A. This is indicated by the branch I of profile B. Occasionally, the plasma potential does not make any such transition and the entire plasma remains at the high potential state (branch II of profile B). To realise the initial conditions it becomes necessary to disturb the device controls like the needle valve which maintains the gas flow or the relative bias between the source and the target chambers.

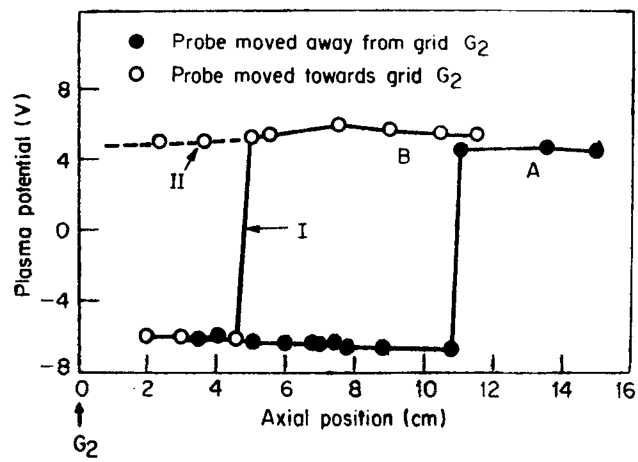

Figure 2. The plasma potential is plotted for various axial positions of the emissive probe. Profile A corresponds to when the emissive probe is moved away from the grid G2 and profile B when the emissive probe is moved towards the grid G2. The dashed line (branch II of the profile B) shows that occasionally the entire plasma remains at high-potential state.

Apparently resetting of the device controls enables one to reduce the ionisation of the neutral gas in the target chamber to an extent that space charge of the electron current is not completely neutralised.

Another feature of these observations is that high-state plasma potential is related to the potential of the grid G2. Figure 3 shows a plot between high-state plasma potential and potential of the grid G2. Although the value of high-state potential is not the same as the potential of the grid G2, there is a good correlation between the two parameters. This indicates that the target plasma has a tendency to attain the potential of the grid G2. Similar observations at other device control settings confirmed that the value of high-state potential can be very close to the potential of the grid G2. It must be remarked here that the potential jump is nearly equal to the voltage difference between the source and the grid G2.

It is certain that the sharp potential jumps observed in our double plasma device are not stationary or moving double layers although all the device controls were carefully set so as to provide appropriate conditions conducive to their formation. Because of a large electric field across a double layer it is expected that electrons and ions are accelerated across the layer. Hence the existence of a double layer has to be verified by the observations of particle acceleration. In our case, the probe data clearly indicates the absence of such electron and ion beams that can be associated with the observed potential jumps. In fact, as mentioned earlier, the plasma in the target region does not contain any beams.

In all respects our observations are similar to those obtained by Coakley and Hershkowitz (1979) in their double plasma device. One may conclude, like these authors have done, that the observed potential jump is due to the fact that plasma in the target region possesses two metastable states. To analyse these observations further we noted the variation of the plasma potential near the grid G2 as the neutral gas pressure was varied after all the device controls were tuned to form a double layer. This is shown in figure 4. It shows that when the neutral

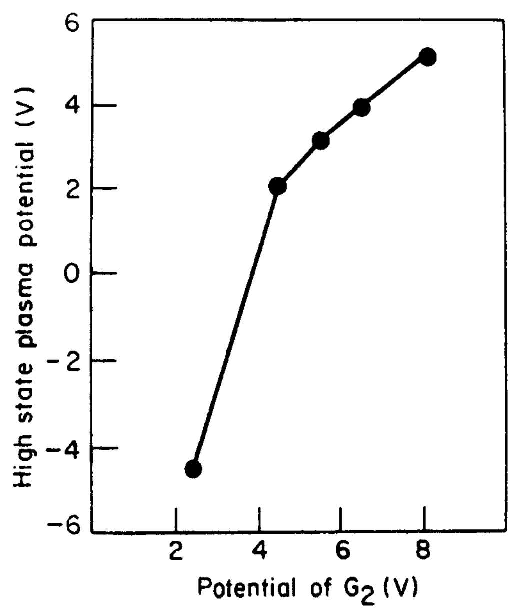

Figure 3. A plot between the high-state potential and the potential of the grid G2.

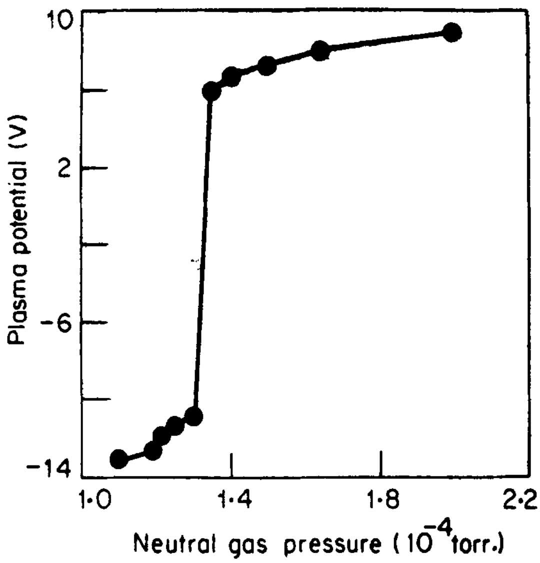

Figure 4. The plasma potential at 10 cm from the grid G2 is plotted for various neutral gas pressures. The device control settings are G1 = O V, G2 = 10 V, G3 is grounded $V_{S-T} = -8{\cdot}3$ V. Note the sharp transition in the plasma potential between $1{\cdot}3 - 1{\cdot}35 \times 10^{-4}$ torr.

gas pressure is changed from $1{\cdot}3 \times 10^{-4}$ torr to $1{\cdot}35 \times 10^{-4}$ torr, the plasma potential makes an abrupt jump from $-13{\cdot}2$ to 6 V. The implication of this figure is that the sharp transition of plasma potential observed in the target region may be due to the ionisation of a minute amount of the neutral gas that leaks into the system during the probe movement. This view is further supported by the observation that potential jumps are observed only when pressure of the neutral gas is critically adjusted. Hence there is no need to invoke the existence of metastable states to explain pseudo-layers observed by Coakley and Hershkowitz (1979) and the potential jumps observed in our device. In this context, we wish to emphasise that for the existence of metastable states, it would become necessary to think of such plasma physical processes which do not depend upon the external factors like gas leakages into the system during the probe movement. Leung *et al* (1980) have reported that similar critical adjustments of the pressure of the neutral gas are also required for producing double layers in the double plasma device. Our results thus clearly emphasise a need for exercising a caution in associating every observed potential jump with a double layer particularly where the layer is delineated by the movement of a probe. Some double-layers like potential jumps are fake and they should be distinguished from the real double layers by the absence of electron/ion beams.

4. Conclusion

In conclusion, the double layers like potential jumps, observed in the present experiments and having characteristics similar to the pseudo double layers reported by Coakley and Hershkowitz (1979), arise only due to ionisation of a very minute amount of additional gas introduced during the probe motion. This results in neutralisation of the electron space charge leading to increase in plasma potential throughout the target plasma region. The observed potential jump thus neither corresponds to the two metastable states of the target plasma nor to the formation of a potential double layer. What remains, however, to be explained is the cause of the additional ionisation in view of the fact that ionisation mean free path does not decrease significantly if the gas pressure changes by a very small fraction of the ambient value. To gain more insight about the phenomenon, further experiments on these lines have been planned.

Acknowledgements

We thank Dr P I John for many stimulating discussions and Mr M Vijayan for help rendered in the reconstruction of this device.

References

Andersson D, Babic M, Sandahl S and Torvén S 1969 *Proc. 9th Int. Conf. Phen. Ionised Gases* (Editura Academici Republicii Socialistic Romania, Bucharest, Romania) p. 142
Block L P 1972 *Cosmic electrodynamics* **3** 349
Coakley P, Hershkowitz N, Hubbard R and Joyce G 1978 *Phys. Rev. Lett.* **40** 230
Coakley P and Hershkowitz N 1979 *Phys. Fluids* **22** 1171
DeGroot J S, Barnes C, Walstead A F and Buneman O 1977 *Phys. Rev. Lett.* **38** 1283
Goertz C K and Joyce G 1975 *Astrophys. Space Sci.* **32** 165
Hudson M K and Mozer F S 1978 *Geophys. Res. Lett.* **5** 131
Knorr G and Goertz C K 1974 *Astrophys. Space Sci.* **31** 209
Leung P, Wong A Y and Quon B H 1980 *Phys. Fluids* **23** 992
Levine J S, Crawford F W and Ilić B D 1978 *Phys. Lett.* **A65** 27
Lutsenko E I, Sereda N D and Kontsevoi L M 1975 *Sov. Phys. (Tech. Phys.)* **20** 498
Montgomery D and Joyce G 1969 *J. Plasma Phys.* **3** 1
Quon B H and Wong A Y P 1976 *Phys. Rev. Lett.* **37** 1393
Raadu M A and Carlqvist P 1979 TRITA-EPP-79-21
Singh N 1979 *Phys. Lett.* **A75** 69
Singh N 1980 *Plasma Phys.* **22** 1
Shawhan S D, Fälthamar C and Block L 1978 *J. Geophys. Res.* **83** 1049
Smith R A and Goertz C K 1978 *J. Geophys. Res.* **83** 2617
Torvén S 1965 *Ark. Phys.* **29** 533
Torvén S 1979 *Waves and instabilities in space plasmas* eds P J Palmdesso and K Papadopoulos (Netherlands: D Reidel Pub. Co.) p. 8