DUST INDUCED QUENCHING OF AN AFTERGLOW PLASMA

K. DIMOFF and P. R. SMY
Department of Electrical Engineering, University of Alberta, Edmonton, Alberta, USA

Received 10 April 1970

The rate of de-ionization of an afterglow plasma is found to increase by a factor of 50 when a cloud of dust particles is injected into the discharge region. This 'quenching' of the plasma is in good agreement with theory.

The interaction of plasmas with micron-sized dust particles enters such diverse fields as energy conversion [1], combustion [2], and recombination phenomena in ionospheric physics [3]. At temperatures greater than 2000°K, individual dust particles constitute a source of free electrons by virture of a work function somewhat less than the ionization potential of the local gas atoms [4]. However, at low temperatures dust particles act to remove free electrons from the plasma.

Measurements have been performed in the afterglow of a pulsed linear discharge where the plasma temperature is well above 2000°K. Nevertheless, it can be shown [5] that the average rise in surface temperature of nickel dust particles will be < 200°K (discharge energy ~ 10^3 joule, duration ~ 20 μs, surface area of discharge chamber ~ 10^3 cm^2). Therefore, any dust particles present can be expected to remain 'cold' and so produce strong 'quenching' (very rapid de-ionization) of the plasma.

A known density of dust (nickel particles, average diameter = 30μ) is injected into the discharge chamber. Immediately after injection, while the dust is still uniformly distributed, a pulsed linear discharge is triggered in the background gas (argon at 1.9 torr pressure). Subsequent variations of plasma ion density are monitored by a double probe technique [6] modified for high pressures [7]. Similar probe measurements in dust-free afterglow plasmas [8] show good agreement with optical [9] and spectroscopic 10] measurements.

Ambipolar diffusion to the walls of the discharge chamber is an important process in ionization decay for plasmas with electron density 10^{12} cm^{-3} (where chamber radius ~ 10 cm and he gas is at 1.9 torr initial pressure) [8,11]. The rate of ionization decay can be markedly increased in the presence of dust. The mean distance of any ion to the nearest solid surface (now a dust particle) becomes reduced by several orders of magnitude. The dust particles in this experiment are smaller than the ion mean free path (100μ). Consequently the ion current (I) flowing to a dust particle can be calculated from conventional theory for a floating spherical Langmuir probe [12].

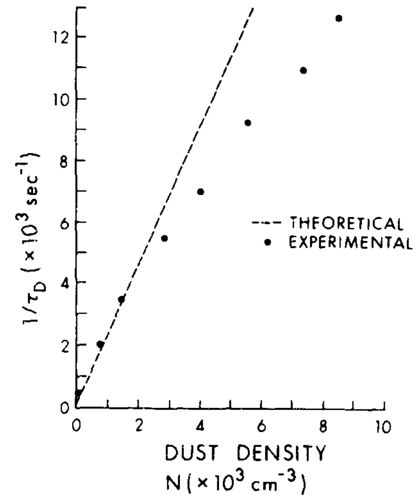

Fig. 1. The dependence of experimental (points) and calculated (line) characteristic de-ionization times (τ_D) on variations in dust density.

For the plasma, (electron density $n_e \approx 5 \times 10^{11}$ cm^{-3}, electron temperature ~ 0.3 eV) the ion temperature is assumed equal to that of the gas (T ~ 0.3 eV from speed of sound measurements). This yields a Debye length ≈ dust particle diameter. Irregularities in particle area (A) due to different size and shape must also be included. These considerations justify the following approximation

$$I \sim A\, e n_e (kT/m_+)^{1/2} \qquad (1)$$

where e = electron charges, k = Boltzmann's constant, m_+ = ion mass.

From eq.(1) the total current to a cloud of dust particles with volume density N cm^{-3} will have a characteristic ionization decay time

$$\tau_D \sim (AN)^{-1}\,(kT/m_+)^{-1/2} \qquad (2)$$

Experimental values of the reciprocal characteristic decay time are found to vary linearly with dust density and are compared in fig. 1 with theoretical values from eq. (2). The agreement between theory and experiment is somewhat better than warranted by the simplifications leading to eq. (2). The significant facts are that the relation is linear and the slope has a magnitude similar to that predicted by theory. Under the given experimental conditions the natural decay of the plasma can be enhanced by a factor of 50.

References

[1] M. S. Sodha and E. Bendor, Brit. J. Appl. Phys. 15 (1964) 103.
[2] K. Gugan, J. Lawton and F. J. Weinberg, Tenth Intern. Symp. on Combustion (Combustion Institute, Pittsburgh, Pa., 1965) p. 709.
[3] R. R. Hodge Jr., Astrophys. Jour. 156 (1969) 2223.
[4] M. S. Sodha, C. J. Palumbo and J. T. Daley, Brit. J. Appl. Phys. 14 (1963) 916.
[5] D. E. T. F. Ashby, J. Nucl. Energy, C, 5 (1962) 83.
[6] E. O. Johnson and L. Malter, Phys. Rev. 80 (1950) 58.
[7] C. H. Su and R. E. Kiel, J. Appl. Phys. 37 (1966) 4907.
[8] J. R. Greig and P. R. Smy, Proc. 7th Int. Conf. on Ionization phenomena in gases, Beograd, 1 (1965) 822.
[9] J. M. P. Quinn, J. Nucl. Energy, C, 7 (1965) 113.
[10] N. J. Peacock and E. T. Hill (1964) Culham Report CLM-M. 27.
[11] A. von Engel, Ionized gases (Clarendon Press, 1955) 123.
[12] J. H. De Leeuw, in: Physico-chemical diagnostics of plasmas, ed. T. P. Anderson (Northwestern University Press, Evanston, Illinois, 1963).

* * * * *

STARK BROADENING FOR TURBULENCE STUDIES IN A CONFINED PLASMA

M. A. LEVINE and C. C. GALLAGHER
Air Force Cambridge Research Laboratories, Bedford, Massachusetts 01730, *USA*

Received 6 April 1970

Plasma turbulence produces enhanced broadening in the wings of Stark broadened profiles. In a toroidal, high β, plasma containment device, this mechanism established the presence of turbulence during the compression phase and the absence of turbulence during containment.

Long term confinement of plasmas has been prevented, in general, by plasma turbulence. Recently, plasma confinement, free of turbulence, has been achieved in a toroidal, high-β device called Tormac [1,2]. A stabilized, toroidal pinch is used to produce a 15 eV plasma of greater than 10^{16} particles/cm^3, which is then confined by a multipole, cusp, magnetic field. The initial plasma containment exhibits a time constant of roughly 100 μsec. The containing field has a shorter time constant, however, and limits total containment time to about 30 μsec. Conclusions on stability were based on optical and magnetic field measurements which showed that the plasma region expanded and cooled in direct proportion to changes in the confining field pressure. Double probe measurements showed that actual plasma losses from the pinch region were small during the period of containment, and no low frequency turbulence was apparent.

Recently, Ben Yosef and Rubin [3], following the work of Griem and Kunze [4] in helium, showed that turbulence in a hydrogen plasma causes an excessive Stark broadening of line profiles not accountable from existing Holtsmark theory. Collective fields, greatly in excess of equipartition values, indicate plasma turbulence and are manifested by broader profiles in the wing regions. The work was performed at low particle densities and comparisons were made to Gaussian approximations for the theoretical profiles.

Similar phenomena was sought from Tormac where a hydrogen plasma at much higher densi-