Laboratori Nazionali di Frascati

LNF-64/32 (1964)

J. E. Allen, A. Turrin: THE COLLECTION OF POSITIVE IONS BY A PROBE IMMERSED IN A PLASMA.

Estratto da: Proc. Phys. Soc. 83, 177 (1964).

PROC. PHYS. SOC., 1964, VOL. 83
Reprinted from
Proceedings of the Physical Society, Vol. 83, Part 1, No. 531, pp.177–179
1964
Printed in Great Britain by J. W. Arrowsmith Ltd., Bristol 3

LETTERS TO THE EDITOR

The collection of positive ions by a probe immersed in a plasma

Abstract. The numerical calculations reported by Allen, Boyd and Reynolds in 1957, which refer to a spherical probe immersed in a low pressure plasma, have been extended to cover a wider range of parameters.

In a paper with the above title (Allen, Boyd and Reynolds 1957) certain numerical calculations were presented referring to a spherical probe immersed in a low pressure plasma. These calculations referred to the growth of the sheath thickness with increasing (negative) potential and to the positive ion current–voltage characteristics of the probe. Since a number of enquiries have been received about these numerical calculations it was decided to compute further curves for different values of the parameters. The purpose of this letter is to present these newly computed curves. Reference should be made to the original paper for a discussion of the limitations of the theory.

The equation describing the distribution of potential near the probe is

$$\eta^{1/2}\xi^2\left[e^{-\eta}+2\left\{\frac{d^2\eta}{d\xi^2}+\frac{2}{\xi}\frac{d\eta}{d\xi}\right\}\right] = \frac{I_2}{I_\lambda} \tag{1}$$

where the potential in dimensionless units is given by $\eta = e_1V/kT_1$ and the normalized distance from the centre of the probe is $\xi = r/\lambda$, where λ is the Debye distance

$$(kT_1/8\pi ne_1{}^2)^{1/2};$$

I_2 is the ion current and I_λ is a characteristic current defined by

$$I_\lambda = (kT_1)^{3/2}/e_2(2m_2)^{1/2}.$$

The suffixes 1 and 2 refer to the electron and positive ion respectively. For large values of ξ the asymptotic form of the equation is

$$\eta^{1/2}\xi^2 e^{-\eta} = I_2/I_\lambda \tag{2}$$

which is known as the 'plasma solution' since it corresponds to quasi-neutrality. To proceed with the numerical integration of equation (1) a new variable $x = \xi(I_\lambda/I_2)^{1/2}$ was therefore introduced and a starting point was chosen on the 'plasma solution' curve at a sufficiently large value of x. Milne's numerical method of integration with variable steps was then employed to calculate η for smaller values of x.

The newly computed curves for $I_2/I_\lambda = 10, 20, 30, 40$ and 80 are given in figure 1 together with those for $I_2/I_\lambda = 120, 160$ and 200, from the original paper. The curve for $I_2/I_\lambda = 80$ was also given in the original paper but has been recalculated starting from a larger value of x ($x = 4$); in this way the accuracy of the calculation has been increased to 3 or 4 significant figures. The surface of the probe corresponds to a vertical line at the appropriate value of ξ and the curves on the right-hand side of this line give the potential distribution in the vicinity of the probe for different values of the probe potential. Thus it can be seen that the sheath region increases in size as the probe is made more negative.

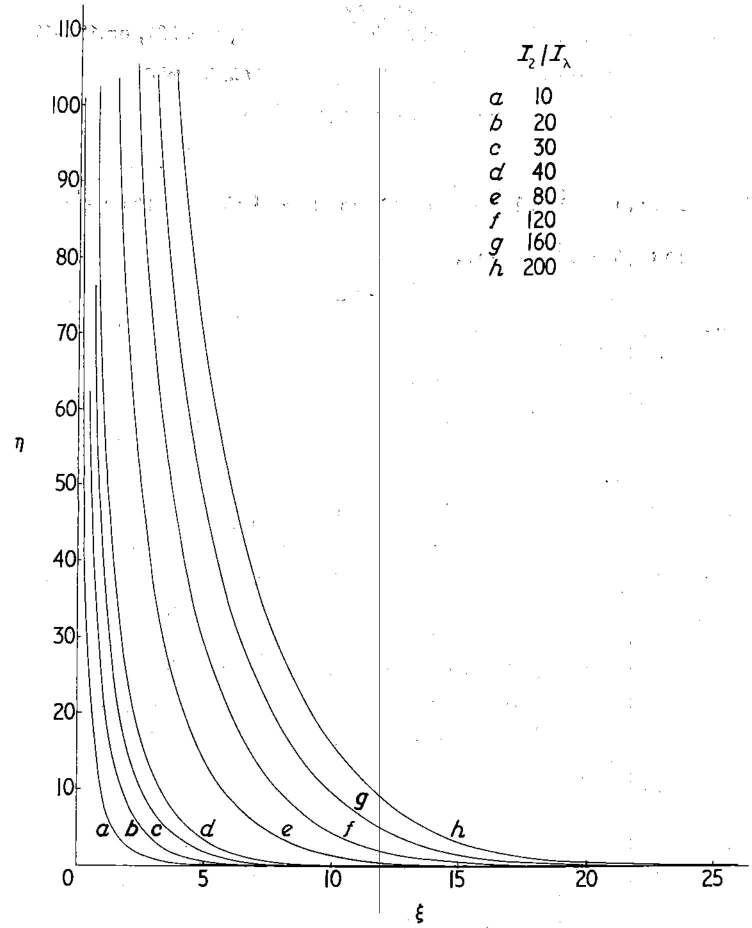

Figure 1. The distribution of potential in the sheath surrounding a spherical probe.

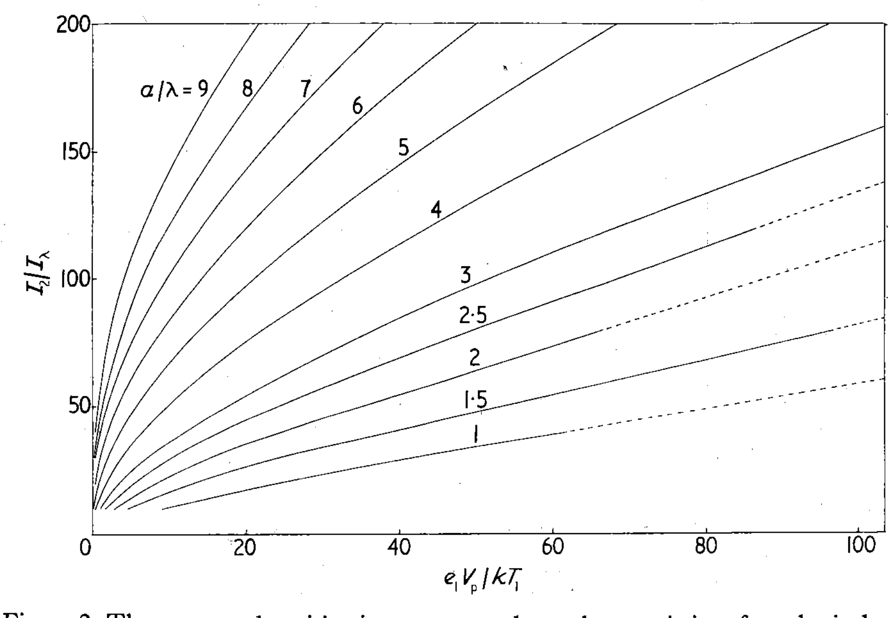

Figure 2. The computed positive ion current–voltage characteristics of a spherical probe.

The positive ion current–voltage characteristics obtained from figure 1 are shown in figure 2 for different values of a/λ, where a is the probe radius. These curves may be employed in the following manner to determine the electron density from measurements of the ion current to a spherical probe. The ion currents should be plotted in the form I_2/I_λ (which entails a knowledge of the electron temperature). The experimental curve should then lie close to one of the curves of figure 2 and the electron density can then be obtained from the corresponding value of a/λ.

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4th November 1963

ALLEN, J. E., BOYD, R. L. F., and REYNOLDS, P., 1957, *Proc. Phys. Soc.* B, **70**, 297.