CHAPTER IV

EVALUATION OF DIFFUSION COEFFICIENT OF ELECTRONS IN A MERCURY ARC PLASMA BY MEASUREMENT OF DIFFUSION CURRENT

4.1. Introduction

In literature there are extensive references regarding the measurement of drift velocity of electrons in ionized gases for a wide range of (E/P) values but corresponding measurements of diffusion coefficient of electrons and ions have not been reported to such a large extent. The earlier methods used for evaluation of diffusion constant of electrons and ions were based on the well known expression $\mu_e / D_e = e / KT_e$ where μ_e the mobility of the electrons was obtained from the experimental measurement of drift velocity and T_e the electron temperature was also obtained from an independent measurement. A systematic investigation regarding the diffusion of slow electrons in nitrogen and hydrogen was carried on by Crompton and Sutton (1952) using a modification of the well-known method of Townsend as suggested by Huxley and Zaazou (1949). They measured the ratio v_d / D_e for (E/P) values varying from .05 to 20 volts/cm torr for both nitrogen and hydrogen and taking the values of V_d from previous measurements of Nielson (1936) evaluated the values of D_e. It was observed that D_e increases with the increase of (E/P). Most of the work reported in the literature regarding measurement of diffusion coefficient refers to measurement of temporal variation of charge density in a decaying plasma and assuming the validity of equation of continuity the value of the diffusion coefficient has been evaluated. Mass spectrometeric measurements have yielded information regarding the nature of ions in case of ionic diffusion. Some measurements have also been reported regarding the variation of diffusion coefficient in either a transverse or a longitudinal magnetic field. Almost all the results reported regarding measurement of diffusion coefficient relate to glow discharge or to a decaying plasma and practically little work on the diffusion process in an arc plasma has been reported. In a recent communication (Sen, Gantait and Acharyya, 1989) the open circulated diffusion voltage in an arc plasma has been measured over a range of arc current and utilizing the radial distribution function of conductivity as introduced by Ghosal, Nandi and Sen (1978) the results have been analysed. Further from the measurement of diffusion voltage in an arc plasma in a transverse as well as in an axial magnetic field (Sen, Acharyya, Gantait and Bhattacharjee, 1989) variation of electron temperature has been investigated. It has been presumed that if the closed circuit diffusion current in an arc plasma can be measured then from the relation

$$I_D = e n_{av} \mu E - e D_e \frac{dn_e}{dr} \quad \ldots(4.1)$$

the diffusion coefficient D_e could be evaluated provided that other quantities such as n_{av} the average electron density and μ_e the mobility coefficient are obtained from an independent observation. Hence in the present investigation it is proposed to measure the diffusion current in an arc plasma for a range of arc cufrent and also at different pressures so as to evaluate the diffusion coefficient of electrons in an arc plasma and study its variation with increasing arc current and pressure.

4.2. Experimental set up

The method of measurement of diffusion voltage in an arc plasma has been discussed in detail in chapter (III). A mercury arc with internal radius 1.1 cm. was used for measurement of diffusion voltage and diffusion current. Separation between the two mercury pool electrodes was 41 cm. Two identical cylindrical probes of length0.8 cm. and diameter .01 cm are placed parallel to one another one along the axis and the other at a distance of0.6 cm. from the axis. The output voltage between the two probes which is the diffusion voltage is measured with a VTVM having an internal impedance of 10 MΩ . A milliammeter connected between the two probes measures the diffusion current. Results are reported for arc current varying from 2 to 5 amp. and for three pressures namely0.075 0.1 and 0.13 torr.

4.3. Results and discussion

The variation of diffusion voltage and diffusion current in the mercury arc plasma against the variation of arc current from 2 A to 5 A has been plotted for a background air pressure of0.075 torr in fig. (4.1) for 0.1 torr in fig. (4.2) and for a pressure of 0.13 torr in fig. (4.3). It is evident that the variation of a diffusion voltage is the same as observed earlier (Chapter III), but the diffusion current increases slowly for small arc current but shows an almost exponential rise with the further increase of arc current. The nature of variation of

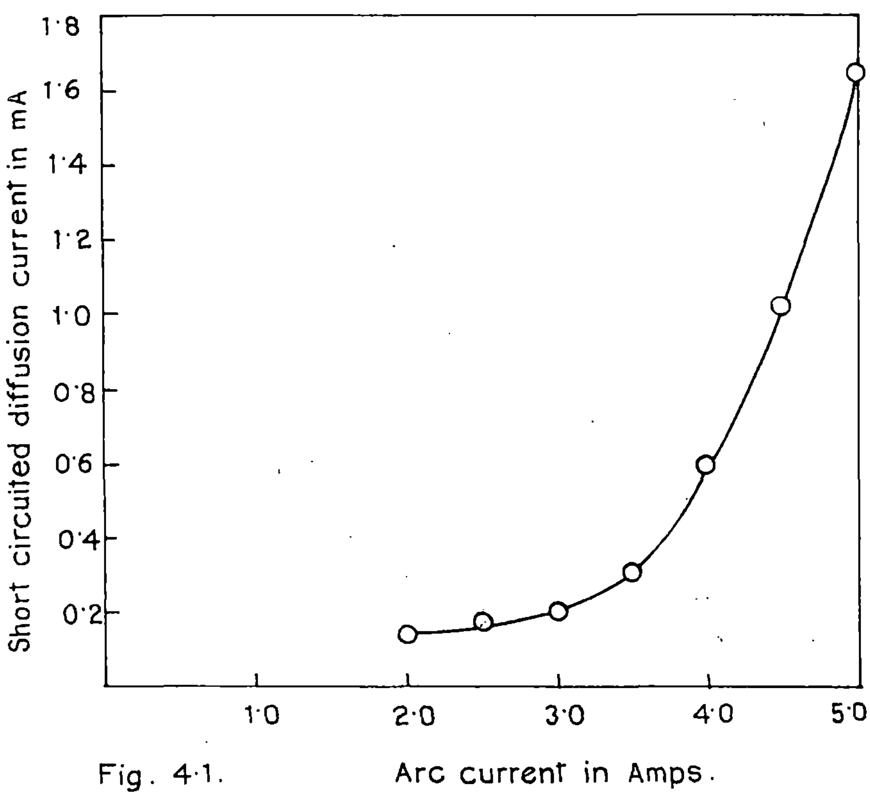
Short circuited diffusion current in mA
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2
1·0
2·0
3·0
4·0
5·0
Arc current in Amps.

Fig. 4·1.

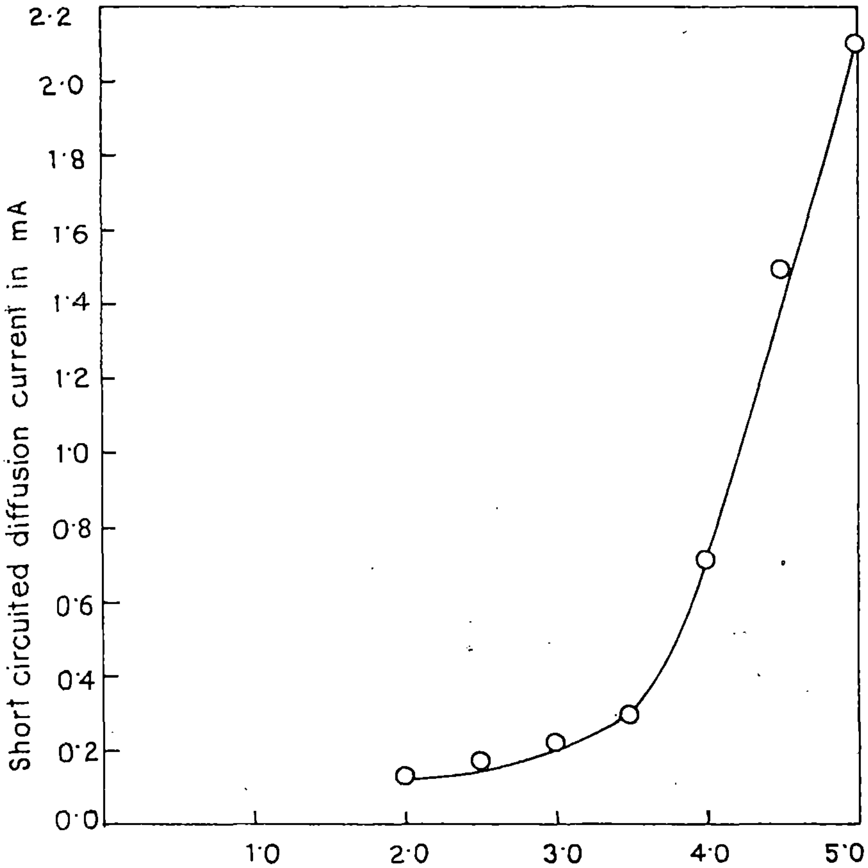

Fig. 4·2. Current in Amps

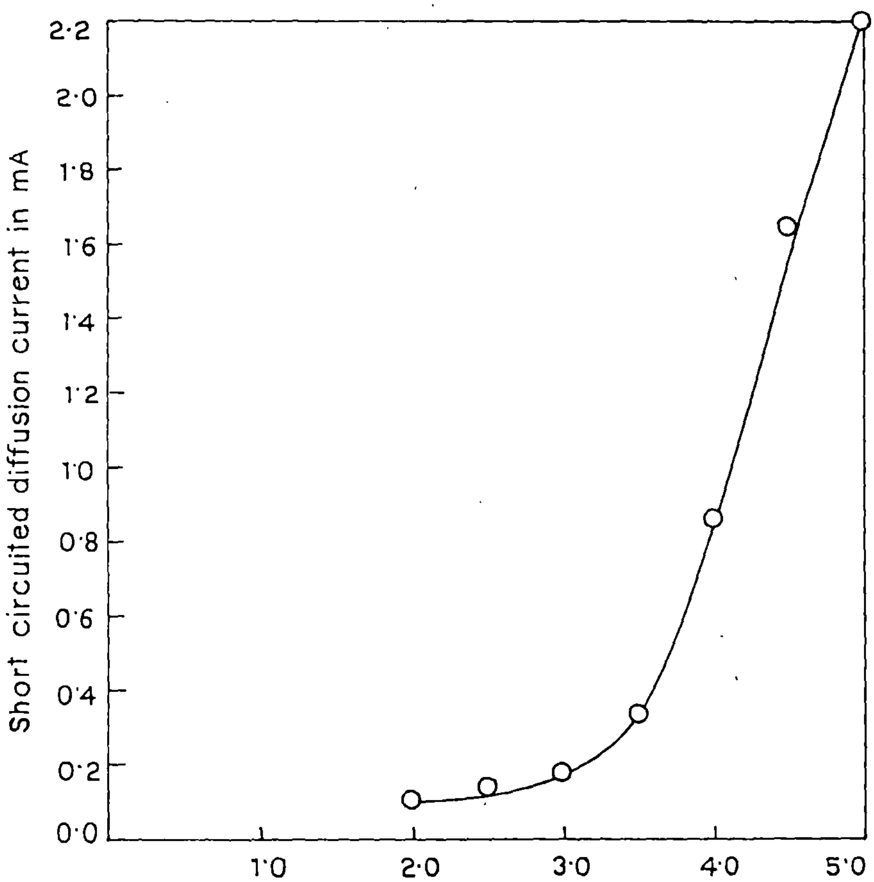

Fig. 4·3 Arc current in Amps.

diffusion current with arc current is of similar nature for all the three pressures. The current which is measured is due to both drift and diffusion and the current density can be written as

$$I_D = \frac{n_o e^2 E}{m \vartheta_c} - eD_e \frac{\partial n_e}{\partial r} \quad \cdots (4.2)$$

where n_o is the average electron density and ϑ_c the collision frequency. In case of an arc plasma it has been postulated by Ghosal, Nandi and Sen (1978) that

$$n_e = n_o [1 - (\frac{r}{R})^2]^n$$

where n is a factor which depends upon arc current (Chapter III).

Hence

$$I_D = \frac{n_o e^2 E}{m \vartheta_c} + \frac{2eDn_o n}{R^2} \left\{ 1 - \frac{r^2}{R^2} \right\}^{n-1} \quad \cdots (4.3)$$

The values of n_o for different arc currents have been obtained in chapter (III) for all the three pressures by independent probe measurements, E as the diffusion voltage drop per cm. which has been evaluated from the measured diffusion voltage drop and ν_c for mercury vapour for the three pressures have been calculated from the relation $\nu_c = v_r / \lambda_e$ where the values of λ_e the mean free path have been obtained in chapter (III) and the value of v_r the random velocity has been collected from McDaniel (1964). Regarding the values of n it is to be noted that some values of n were obtained by Ghosal, Nandi and Sen (1978) but a measurement of n for a wider range of current has been recently carried out in this laboratory and the variation in the value of n with arc current has been plotted in fig. (3.1, 3.2, 3.3) chapter (III). Thus the values of n_e , E, ν_c and n are entered in Table (4.1), (4.2), (4.3) for three different pressures. The corresponding values of D_e are entered in the last column in each table.

From the tabulated results, it is observed that the diffusion coefficient of electrons in mercury vapour in an arc varies from 673 cm^2/sec to 1717 cm^2/sec at a pressure of0.075 torr, from 512 cm^2/sec to 2500 cm^2/sec for a pressure of 0.1 torr and from 395 cm^2/sec to 1765 cm^2/sec at a pressure of0.13 torr for arc current varying from 2 to 4.5 amps. in each case. We have not come across any experimental

Table 4.1.

P = 0.075 torr

Arc current in Amp.	Diffusion current in mA	Diffusion voltage drop/cm.	Value of n_e x 10^{-12}	δ_c x 10^{-9}	n	$(1-\frac{r^2}{R^2})^{n-1}$	D_e x 10^{-4} $cm^2 sec^{-1}$
2.0	0.14	0.83	1.2476		1.65	0.7949	0.06739
2.5	0.17	0.783	1.4297		1.7149	0.7769	0.070305
3.0	0.22	0.73	1.8167	6.38	1.7446	0.7688	0.071125
4.0	0.60	0.863	2.5962		1.9667	0.7108	0.13023
4.5	1.02	1.1167	3.2832		2.1059	0.6767	0.1717

values for electron diffusion in mercury vapour in literature and consequently the accuracy of the results obtained by this method could not be verified. However, it is noted that the diffusion coefficient of mercury as obtained in this investigation is approximately one order of magnitude smaller than the corresponding values for hydrogen and nitrogen as reported by Crompton

Table 4.2

P = 0.1 torr.

Arc current in Amp.	Diffusion current in mA.	Diffusion voltage drop/ cm.	Value of $n_e \times 10^{-12}$	$\delta_c \times 10^{-9}$	n	$(1-\frac{r^2}{R^2})^{n-1}$	$D_e \times 10^{-4}$ $cm^2 sec^{-1}$
2.0	0.12	0.7633	1.4068		1.65	0.7949	0.05123
2.5	0.16	0.73	1.5721	8.814	1.7149	0.7769	0.0601
3.0	0.20	0.725	1.8686		1.7446	0.7688	0.06286
4.0	0.72	0.927	2.6451		1.9667	0.7108	0.1534
4.5	1.50	1.167	3.3164		2.1059	0.6767	0.25000

and Sutton (1952). From the theory which assumes that collision is the main factor responsible for diffusion it can be deduced that the diffusion coefficient of electrons D_e in an ionised gas is given by $D_e = 1/3\,\lambda_e V_e$ where λ_e is the mean free path of electron and V_e is the random velocity of electrons in the gas. In general it may be assumed that $v_e = 10^8$ cm/sec and λ_e is of the order of

Table 4.3

P = 0.13 torr.

Arc current in Amps	Diffusion current in mA	Diffusion voltage drop/cm.	Value of n_e $x10^{-12}$	ν_c $x10^{-9}$	n	$(1-\frac{r^2}{R^2})^{n-1}$	D_e x 10^{-4} $cm^2 sec^{-1}$
2.0	0.10	0.7433	1.5173		1.65	0.7949	0.03958
2.5	0.14	0.7083	1.7106		1.7149	0.7769	0.04839
3.0	0.18	0.6833	2.0271	10.286	1.7446	0.7688	0.05215
4.0	0.86	0.95	2.7444		1.9667	0.7108	0.17658

10^{-2} cm, so that D_e comes out to be of the order of 10^6 $cm^2 sec^{-1}$, but actually electrons in their motion through the gases induce dipoles and as a result the effective mean free path is reduced due to polarization, consequently the actual diffusion coefficient is reduced by at least one order of magnitude or may be more. The order of magnitude for the diffusion coefficient for the electrons in mercury vapour thus seems to be of the right order of magnitude. Further the mean free path of electrons in an ionised gas depends upon the energy of the electrons according to Townsend, Ramsauer effect and hence will depend upon the arc current which is a function of the velocity and so of the energy of the electrons. Consequently the diffusion coefficient of the electrons will be a function of the arc current as is observed in the present investigation and also observed by Crompton and Sutton (1952) for increasing values of (E/P). Further it is observed from the present experimental results that the diffusion coefficient decreases with the increase of pressure which is consistent with the theoretical expression that diffusion coefficient is directly proportional to mean free path. It is further noted that the diffusion coefficient increases with the increase of arc current for the three pressures investigated here which may be due to the fact with the increase of arc current, temperature of the mercury vapour increases as has been measured by Sadhya and Sen (1980) and as v_e is proportional to $T^{1/2}$ for the same pressure D_e should increase with the increase of temperature and hence with arc current.

In an earlier paper by Sadhya and Sen (1980) the detailed physical processes occuring in an arc plasma have been investigated and a model has been developed in which air plays the role of a quenching gas and it has been found that in this type of discharge both atomic and molecular ions of mercury are present but the number of free electrons is much greater than those of atomic and molecular ions and so it can be assumed that the diffusion coefficient measured here represents diffusion by electrons mainly. A mass spectrometric analysis would have provided the relative number of atomic and molecular ions present. Further the physical processes occuring in an arc plasma are different from those occuring in a glow discharge and no consistent theory has been developed regarding diffusion process in an arc plasma. It is expected that the values obtained here for electron diffusion in the mercury vapour may be useful in developing a theory for diffusion process in an arc discharge.

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