CHAPTER IV

EVALUATION OF ELECTRON TEMPERATURE IN GLOW DISCHARGE FROM MEASUREMENT OF DIFFUSION VOLTAGE

It is well known that if D_e and D_i represent the electronic and ionic diffusion coefficients of electrons and ions in a partially ionised gas, then

$$D_e = \frac{1}{3} \lambda_e v_e \quad \text{and} \quad D_i = \frac{1}{3} \lambda_i v_i$$

where λ_e is the mean free path for electron neutral atom collision and λ_i is the mean free path for ion neutral atom collision and v_e and v_i are the random velocities for electron and ion respectively. As a general rule these two mean free paths are almost equal but at a given temperature, $v_e \gg v_i$ and hence electrons will diffuse more quickly than the ions. As a result a charge separation will take place and a space charge electric field will be established which will retard the diffusion of electrons and accelerate that of the ions so that ambipolar losses are equalised. If it is assumed that due to charge separation an electric field E is established and as the major part of diffusion is along the azimuthal direction, the field is radial then the ion current due to diffusion along the radial direction

$$I_i = -e D_i \frac{\partial n_i}{\partial r} + e \mu_i E_r n_i$$

$$e n_i v_i = -e D_i \frac{\partial n_i}{\partial r} + e \mu_i E_r n_i$$

$$v_i = -\frac{D_i}{n_i} \frac{\partial n_i}{\partial r} + \mu_i E_r.$$

In the same way for the electrons we get

$$v_e = -\frac{D_e}{n_e} \frac{\partial n_e}{\partial r} - \mu_e E_r.$$

Then $v_e - v_i = -E(\mu_e - \mu_i) - \frac{D_e}{n_e} \frac{\partial n_e}{\partial r} + \frac{D_i}{n_i} \frac{\partial n_i}{\partial r}.$

The effect of space charge electric field is to equalise the velocity so that $v_e = v_i$ then we get

$$E_r(\mu_e - \mu_i) = -\frac{D_e}{n_e} \frac{\partial n_e}{\partial r} + \frac{D_i}{n_i} \frac{\partial n_i}{\partial r}.$$

Due to charge neutrality $n_e = n_i = n$.

$$E_r(\mu_e - \mu_i) = -\frac{1}{n}\frac{\partial n}{\partial r}(D_e - D_i)$$

$$E_r\left(\frac{D_e e}{KT_e} - \frac{D_i e}{KT_i}\right) = -\frac{1}{n}\frac{\partial n}{\partial r}(D_e - D_i)$$

As in the case of ambipolar diffusion if we assume

$$T_e = T_i$$

$$\frac{E_r e}{KT_e}(D_e - D_i) = -\frac{1}{n}\frac{\partial n}{\partial r}(D_e - D_i)$$

$$E_r = -\frac{1}{n}\frac{\partial n}{\partial r}\frac{KT_e}{e} \tag{4.1}$$

Equation (4.1) shows that if T_e is constant then the radial electric field is a function of r. Since it is known that the field is varying, the equation cannot be used for the measurement of T_e. If however, voltage V_R between the axis and some point at a distance r away is measured then

$$V_R = \int E_r\,dr = -\int \frac{dn}{n}\frac{KT_e}{e} \tag{4.2}$$

In the case of an uniformly positive column of a glow discharge the distribution is

$$n = n_0 J_0 (2 \cdot 405\, r/R)$$ Besselian where R is the radius of the discharge tube, so that

$$\frac{K T_e}{e} = \frac{V_R}{\log J_0 (2 \cdot 405\, r/R)} \qquad (4.3)$$

It is thus evident that if V_R can be measured then the electron temperature can be obtained from eqn.(4.3)

Experimental Arrangement

The experimental arrangement has been given in ChapterII

Results and Discussion

The results are consistent with the literature value (von Engel, 1958). When a transverse magnetic field B is present, the plasma is compressed towards the wall and the radial distribution of charged particles chamges.

Sen & Gupta (1971) have shown that, at a distance 'r' from the axis, if n_B and n represent the electron densities in presence of and in absence of magnetic field respectively, then

$$n_B = n \exp(-aB)$$

where $$a = \frac{e E C_1^{1/2} r}{2 K T_e P}$$

where the symbols have their usual significance and

$$C_1 = \left(\frac{e}{m} \frac{L}{v_r} \right)^2$$

where L being the mean free path of the electron at a pressure of 1 torr and v_r is the random velocity of the electron so that C_1 is the square of mobility of the electron at 1 torr.

when r = 0, a = 0, $n_0 B = n_0$

then as before, integrating we get

$$\frac{K T_{eB}}{e} = \frac{V_{RB}}{\log \left[J_0 (2.405\, r/R) \exp(-aB) \right]}$$

The value of 'a' has been calculated from the known values of T_e as obtained here and the calculated value of 'a' is 0.0126.

Hence by placing the discharge tube in transverse magnetic field, the electron temperature has been measured by utilizing the above equation for magnetic field varying from 0 to 100 Gauss for a constant discharge current of 2.8 mA.

It has been reported by Sadhya and Sen that a theoretical expression

$$\left[\frac{T_{eB}^{2}}{T_e^{2}} - 1 \right] = C_1 \frac{B^2}{P^2}$$

is valid for low values of magnetic field in case of hydrogen and helium.

Table 4.1

Variation of $\left(T_{eB}^2 / T_e^2 - 1 \right)$ with $\left(B^2/P^2 \right) \times 10^{-3}$

$B^2/P^2 \times 10^{-3}$ $G^2/Torr^2$	$\left(T_{eB}^2 / T_e^2 - 1 \right)$
16	1.9
36	4.2
64	7.1
100	10.35
143.5	14.05

Table 4.1 shows the variation of ($T_{eB}^2 / T_e^2 - 1$) against B^2/P^2 in air. The agreement between the theory and experiment is quite good for low values of magnetic field and the curve is a straight line from which the value of $C_1 = 1.67 \times 10^{-4}$.

The quantity C_1 is the square of the mobility of the electron at 1 torr and its calculated value is in agreement (at least in order of magnitude) with the value given by Brown for the value of (E/P) reported here.

This is a straightforward and simple method and the only quantity to be measured accurately is the voltage between the central probe ($r = 0$) and a parallel probe placed at a convenient distance.

No further calculations are necessary and hence this method is more advantageous and accurate than the probe method. The error in the measurement of T_e is thus considerably minimized.

Further the proposed method can be utilised for measurement of electron temperature in a magnetic field, specially for low values of (B/P). At high values of magnetic fields the equation $\left[\frac{T_{e\beta}^2}{T_e^2} - 1\right] = C_1 \frac{\beta^2}{p^2}$ becomes invalid because the simplied assumption of Beckman from which the formula is derived no longer holds good.

Thus it is evident from this chapter that the electron temperature in the positive column of a glow discharge can be calculated by measuring the radial d.c. voltage that developes between the probes due to the charge separation of electrons and ions subject to ambipolar diffusion and the method of measurement can be extended in presence of magnetic field as well. The method is simple and straightforward and the possibility of error is minimised.

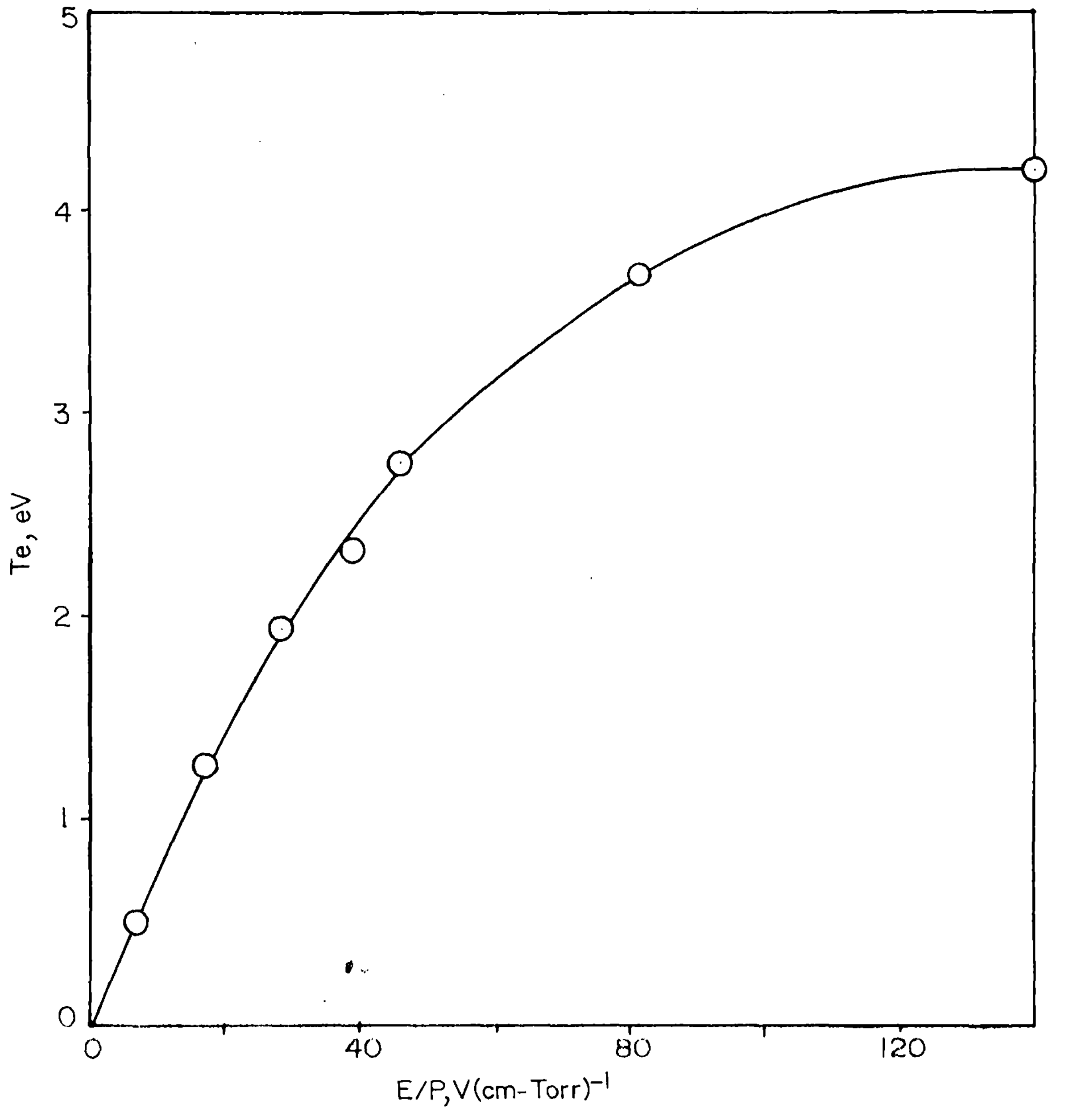

Fig. (4·1) Variation of T_e with E/P in air

P = 1 torr

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Evaluation of Electron Temperature in Glow Discharge from Measurement of Diffusion Voltage

S N SEN, S K GHOSH & B GHOSH
Department of Physics, North Bengal University, Darjeeling 734 430

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It is shown that the electron temperature in a cylindrical glow discharge column can be evaluated by measuring the radial diffusion voltage due to charge separation. The effect of a transverse magnetic field on electron temperature has also been investigated.

It is well known that in the positive column of a glow discharge due to different rates of diffusion of electrons and ions, an electric field develops as a result of charge separation and this field is effective in equalizing the diffusion rates and the phenomenon of ambipolar diffusion results. As the major part of diffusion is along the azimuthal direction, the field is radial. The radial field E_r is given by

$$E_r = -\frac{1}{n}\cdot\frac{dn}{dr}\cdot\frac{KT_e}{e} \quad \ldots (1)$$

where n is the charged particle density and other symbols have their usual significance. Eq (1) shows that if T_e is constant then the radial electric field is a function of r. Since it is known that the field is varying, the equation cannot be used for the measurement of T_e. If however, the voltage V_R between the axis and some point at a distance r away is measured then,

$$V_R = \int E_r dr = -\int \frac{dn}{n}\cdot\frac{KT_e}{e}$$

In the case of a uniformly positive column of a glow discharge, the distribution is Besselian

$$n = n_0 J_0(2.405\, r/R)$$

where R is the radius of the discharge tube so that

$$\frac{KT_e}{e} = \frac{V_R}{\log J_0(2.405\, r/R)} \quad \ldots (2)$$

It is thus evident that if V_R can be measured then the electron temperature can be obtained from Eq. (2).

The experimental assembly consists of a discharge tube of length 10 cm in which the ionized gas under investigation is produced, and the pressure is measured by an accurately calibrated Pirani gauge. Two cylindrical probes of length 1 cm and diameter 0.01 cm are placed parallel to one another, one along the axis $r = 0$ and the other at a distance $r = 0.9$ cm from the axis; the radius of the discharge tube being 1.6 cm.

The output voltage at the two probes is measured by a VTVM having an internal impedance of 100 MΩ. A filter circuit is provided at the output of the probes to prevent oscillations generated in the plasma from reaching the VTVM. The output voltage has been measured for different (E/P) values in air, where E is the axial filed, i.e. the voltage per cm length of the positive column and P is the pressure in Torr. The axial field E is determined by measuring the voltage between the two extra probes at a distance of 5 cm placed in the positive column. The variation of T_e with (E/P) has been presented in Fig. 1. The results are consistent with literature values (von-Engel[1]).

When a transverse magnetic field B is present, the plasma is compressed towards the wall and the radial distribution of charged particles changes. Sen and Gupta[2] have shown that, at a distance r from the axis, if n_B and n represent the electron densities in presence of and in absence of magnetic field respectively, then

$$n_B = n\exp(-aB)$$

$$\text{where} \quad a = \frac{eEC_1^{1/2} r}{2KT_e P}$$

where the symbols have their usual significance and $C_1 = (e/m\,.\,L/v_r)^2$, L being the mean free path of the electron at a pressure of 1 Torr and v_r is the random velocity of the electron, so that C_1 is the square of mobility of the electron at 1 Torr. When $r = 0$, $a = 0$, $n_{0B} = n_0$, then as before, integrating we get,

$$\frac{KT_{eB}}{e} = \frac{V_{RB}}{\log[J_0(2.405\, r/R)\exp(-aB)]} \quad \ldots (3)$$

The value of a has been calculated from the known values of T_e as obtained here and the calculated value of a is 0.0126.

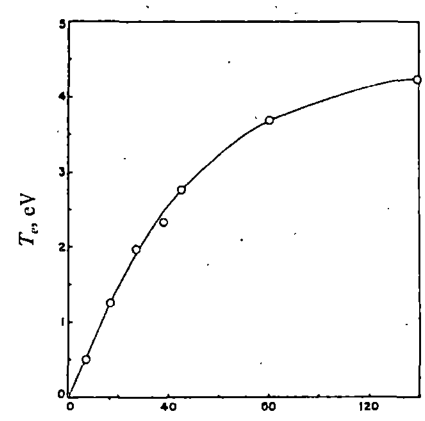

Fig. 1—Variation of T_e with E/P in air [$P = 1$ Torr]

Hence by placing the discharge tube in a transverse magnetic field, the electron temperature has been measured utilizing Eq. (3) for magnetic fielos varying from 0 to 100 Gauss for a constant discharge current of 2.8 mA. It has been reported by Sadhya and Sen[3] that the theoretical experession:

$$\left[\frac{T_{eB}^2}{T_e^2} - 1\right] = C_1 \frac{B^2}{P^2} \quad \ldots (4)$$

is valid for low values of magnetic field in case of hydrogen and helium. Table 1 shows the variation of $(T_{eB}^2/T_e^2 - 1)$ against B^2/P^2 in air. The agreement between theory and experiment is quite good for low values of magnetic field and the curve is a straight line from which the value of $C_1 = 1.67 \times 10^{-4}$. The quantity C_1 is the square of the mobility of the electron at 1 Torr and its calculated value is in agreement (at least in order of magnitude) with the value given by Brown[4] for the value of (E/P) reported here. This is a straightforward and simple method and the only quantity to be measured accurately is the voltage between the central probe ($r=0$) and a parallel probe placed at a convenient distance. No further calculations are necessary and hence this method is more advantageous and accurate than the probe method. The error in the measurement of T_e is thus considerably minimized.

Further, the proposed method can be utilized for measurement of electron temperature in a magnetic field, specially for low values of (B/P). At high values of magnetic field Eq. (4) becomes invalid because the simplified assumptions of Beckman[5] from which the formula is derived no longer holds good.

Table 1—Variation of $(T_{eB}^2/T_e^2 - 1)$ With $(B^2/P^2) \times 10^{-3}$

$B^2/P^2 \times 10^{-3}$ G^2/Torr^2	$(T_{eB}^2/T_e^2 - 1)$
16	1.9
36	4.2
64	7.1
100	10.35
143.5	14.05

The purpose of this note is thus to show that the electron temperature in the positive column of a glow discharge can be calculated by measuring the radial dc voltage that develops between the probes due to the charge separation of electrons and ions subject to ambipolar diffusion, and the method of measurement can be extended in presence of magnetic field as well. The method is simple and straightforward and the possibility of error is minimized.

References

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5 Beckman L, *Proc Phys Soc London, (GB)*, 61 (1948) 515.