CHAPTER V

LOW DENSITY PLASMA IN A MAGNETIC FIELD

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When a magnetic field acts upon a low density plasma as in the case of glow discharge, various changes such as increase of equivalent pressure, decrease in length of cathode dark space, a change in radial ion density in the positive column and marked changes in the voltage current characteristics of the discharge take place. Theoretical interpretation of the phenomena has been provided by Townsend (1938) and by Allis and Allen (1937) who have investigated the motion of electrons in the presence of electric field, a magnetic field and a concentration gradient. Most of the experimental works have been done in longitudinal magnetic field. The effect of a transverse magnetic field on the positive column as regards the electron temperature, electric field and electron density has been calculated by Beckman (1948) on a theoretical basis and the calculations agree fairly well with the experimental results obtained in the case of hydrogen, nitrogen , neon and helium. The general effects of a transverse magnetic field have been investigated by McBee and Daw (1955) on an unconfined glow discharge in air within the pressure range of 0.3 to 10 torr and discharge current from 0.05 to 2.5 Ampere with the magnetic field varying from zero to 7000 gauss. They found with probe measurements that the anode and cathode fall first decrease and then increase, along with this the positive column and the anode region become more luminous. The variation of discharge current in a transverse magnetic field (0 to 3000 Gauss) has been studied by Sen and Gupta (1971) in the positive column of a glow discharge in air, carbondioxide, hydrogen, helium and neon within the pressure range of 80 to 200m torr. The current increases with the magnetic field and shows a maximum at a particular value of the magnetic field which is the same for all the gases and independent of pressure for the same initial discharge current. Utilizing Beckman's expression (1948) for the axial electric field and the radial electron density in presence of a transverse magnetic field a detailed mathematical theory was advanced which could explain the results satisfactorily. Besides the change in these parameters, magnetic field in a low density plasma will produce Hall effect and also affect the process of diffusion.

A method has been suggested by Sen, Ghosh and Ghosh (1983) for evaluation of electron temperature in a glow discharge by measurement of diffusion voltage. In presence of magnetic field, however, the voltage which is measured between the two probes one at the axis and other away from the axis will be affected both by the diffusion process and the Hall voltage developed between the probes. Hence to calculate the electron temperature in a transverse magnetic field by the methods suggested by Sen, Ghosh and Ghosh (1983) the two processes are to be separated and only the diffusion voltage has to be taken into consideration in calculating the electron temperature from

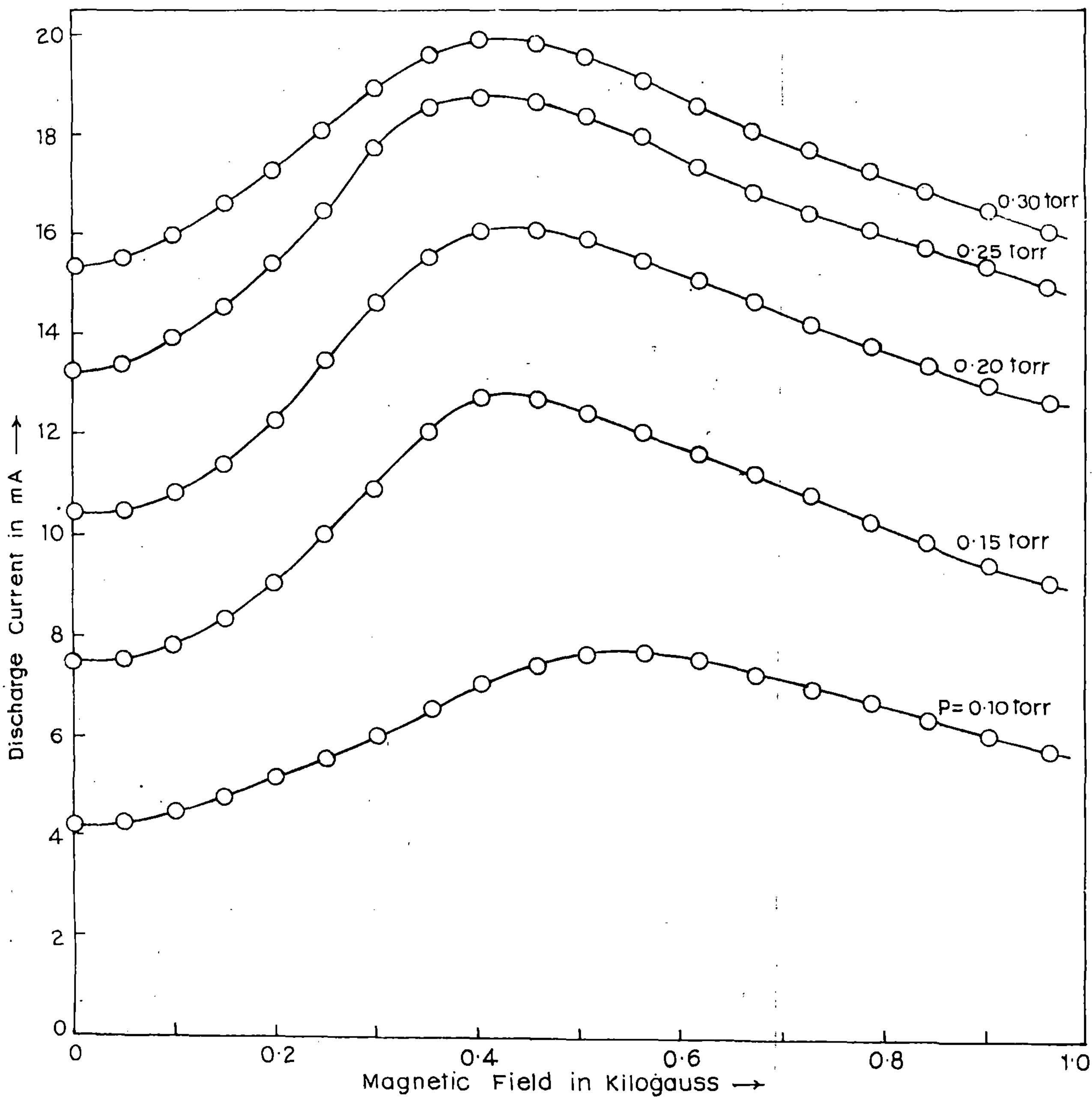

0·30 torr
0·25 torr
0·20 torr
0·15 torr
P= 0·10 torr
Discharge Current in mA →
Magnetic Field in Kilogauss →
0
2
4
6
8
10
12
14
16
18
20
0·2
0·4
0·6
0·8
1·0

Fig. 5-a.

the expression (Sen, Ghosh and Ghosh, 1983)

$$\frac{kT_{eH}}{e} = \frac{V_{RH}}{\log[J_o(2{\cdot}405\frac{r}{R})\exp(-aH)]} \tag{5.1}$$

where, in presence of magnetic field, T_{eH} is the electron temperature and V_{RH} is the diffusion voltage measured between the probes and

$$a = \frac{eErc_1^{1/2}}{2kT_eP} \quad \text{and} \quad c_1 = \left(\frac{e}{m}\cdot\frac{L}{v_r}\right)^2$$

E is the axial voltage drop per cm of the discharge. L is the mean free path at 1 torr, v_r is the random velocity of electrons and r is the distance between the probes.

Results and discussion

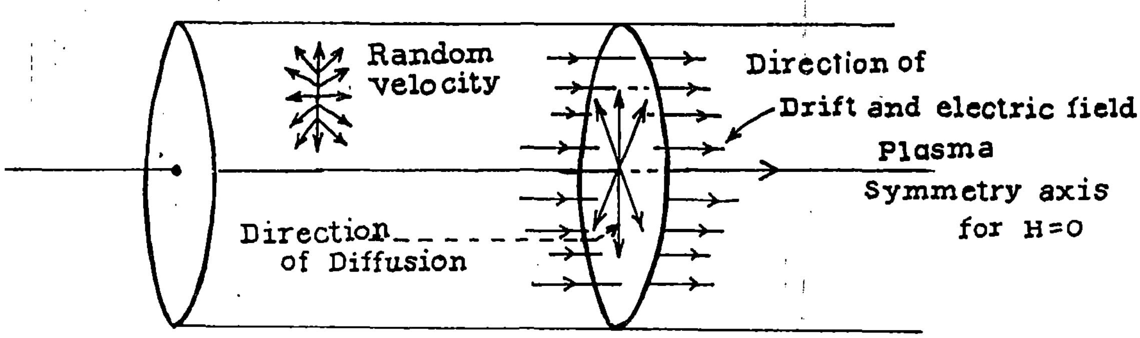
In the first part of the work, the variation of discharge current in air at different pressures where a transverse magnetic field is present has been measured. The results are presented in Fig. 5a for pressures 0.10, 0.20, 0.25 and 0.30 torr with magnetic field varying from zero to 900 gauss. It is observed that the current gradually rises (Table 5-IV, Fig. 5a) and attains a maximum value near about the magnetic field of 400 gauss for all the pressures and then gradually decreases. Similar results have been previously obtained by Sen and Gupta (1971) in case of air and other gases. The results were explained by assuming the effect of magnetic field on the axial electric field and radial electron density distribution and it was shown that the magnetic field at which the discharge current became a maximum was given by

$$H_{max} = 12\cdot 41 \times 10^{-2} (T_e/k)^{\frac{1}{2}} \tag{5.2}$$

where T_e is the electron temperature and k is the Boltzman constant. The value of the magnetic field as calculated from equation 5.2 was in very good agreement with observed experimental results. Since the main object of this investigation is to study the effect of diffusion of charged particles in the magnetic field in a low density plasma the whole physical process occurring in a magnetised plasma has been reconsidered.

It is observed from the present experimental work that the current through the glow discharge plasma changes in presence of transverse magnetic field. Also the process of diffusion changes in a transverse magnetic field. Since the drift current and diffusion are basically controlled by the random velocity of electrons and ions in a plasma, there must be a change in the random and drift velocity of electrons and ions under the action of transverse magnetic field. We can, however, neglect the change in drift and random velocity of ions because of their large mass and hence low contribution to the flow rate either in case of current or in case of diffusion. Since the flow of electrons towards the direction of drift and towards the direction of diffusion comes from the same plasma space, there must be an increase in the electron flow rate in the direction of diffusion if there is a decrease in the direction of drift velocity and vice versa.

If this really happens within the plasma space under the influence of transverse magnetic field, the change in the mean flow rate of electrons v_{DH} towards the direction of diffusion per unit v_{DH} per unit magnetic field must be same as the change in the current density, j_H, at the place of diffusion per unit current density, j_H, per unit magnetic field. The mean flow rate towards diffusion is the flow rate averaged over the entire cross section at any place within the cylindrical plasma column.



Cylindrical Plasma

The velocity of diffusion v_{DH} in a transverse magnetic field, H, is given by

$$v_{DH} = D_H \frac{1}{n_H} \frac{dn_H}{dr} \qquad (5.3a)$$

where D_H, n_H and (dn_H/dr) are the diffusion constant, concentration of electrons and concentration gradient along radial direction respectively and all in presence of transverse magnetic field. Thus the mean flow rate U_{DH} is given by,

$$U_{DH} = \frac{\int_0^R \upsilon_{DH}\, n_H\, dr}{\int_0^R dr} = \frac{1}{R} D_H n_H \qquad (5.3b)$$

Hence according to the assumption,

$$\frac{1}{U_{DH}} \frac{dU_{DH}}{dH} = \frac{1}{J_H} \frac{dJ_H}{dH} \qquad (5.4a)$$

or $$\frac{D_H \frac{dn_H}{dH} + n_H \frac{dD_H}{dH}}{D_H n_H} = \frac{n_H \frac{d\upsilon_H}{dH} + \upsilon_H \frac{dn_H}{dH}}{n_H \upsilon_H}$$

where υ_H is the drift velocity of electrons.

Thus we have,

$$\frac{1}{D_H} \frac{dD_H}{dH} = \frac{1}{\upsilon_H} \frac{d\upsilon_H}{dH} \qquad (5.4b)$$

But the contribution of diffusion term i.e., the left hand term of equation 5.4a, receives the contribution of electrons from either of the random stream of electrons. One of the random stream moves in the direction of drift while the other moves opposite to the direction of drift. But these two streams moving by the random velocity of electrons, have almost same concentration. Slight difference may arise due to drift velocity which is usually small compared to random velocity and hence the difference in concentration between the two oppositely moving streams may be neglected. Thus only half of the electron concentration moving along drift contributes to the drift current while twice of that concentration contributes to diffusion. So only half of the contribution of the diffusion term should be taken into consideration. Thus we have,

$$\frac{1}{2}\,\frac{1}{D_H}\,\frac{dD_H}{dH} = \frac{1}{\vartheta_H}\,\frac{d\vartheta_H}{dH} \qquad (5.5)$$

However, these two terms in 5.5 cannot be exactly equal because some of the particles which are moving parallel to the magnetic field will not be affected but they will still contribute to the process of diffusion. So we assume that

$$\frac{1}{2}\,\frac{1}{D_H}\,\frac{dD_H}{dH} - \frac{1}{\vartheta_H}\,\frac{d\vartheta_H}{dH} = b \qquad (5.6)$$

where b will be a constant at a particular pressure. Now

$$D_H = \frac{D_0}{1 + \omega_H^2 \tau^2}$$

fow low density plasma, where ω_H is the electron cyclotron frequency and τ is the collision time between an electron and atom. So,

$$\omega_H^2 \tau^2 = \left(\frac{eH}{m} \cdot \frac{\lambda_e}{v_r}\right)^2 = \left(\frac{e}{m} \frac{L}{v_r}\right)^2 \frac{H^2}{p^2}$$

Where L is the mean free path of the electron in the gas at a pressure of one torr and P is the pressure. So putting

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

We have, $$D_H = \frac{D_0}{1 + C_1 H^2/p^2} \tag{5.7}$$

So from equation 5.6 and 5.7, we get

$$\frac{1}{v_H} \frac{d v_H}{d H} + b = \frac{C_1 H/p^2}{1 + C_1 H^2/p^2} \tag{5.8}$$

We have neglected the sign because in this discussion we are concerned only with the values of the terms. Now equation 5.8 depicts the exact situation, such that the left hand contribution due to change in current added to the constant b exactly equals the right hand contribution due to change in flow by diffusion. From 5.8, integrating from zero to H, we get

$$v_H = v_o (1 + C_1 H^2/p^2)^{1/2} \; e^{-bH} \tag{5.9}$$

The concentration of charged particles also suffers change in presence of magnetic field and if n_o and λ_o are the electron density and mean free path in absence and n_H, λ_H are the corresponding quantities in presence of magnetic field, then

$$n_o \lambda_o = n_H \lambda_H$$

considering that the number within a mean free path does not change.

Now, $\lambda_H = \lambda_o / (1 + C_1 H^2/p^2)^{1/2}$ [Blevin and Haydon (1958)]

So, $$n_H = n_o (1 + C_1 H^2/p^2)^{1/2} \tag{5.10}$$

Hence the current density in presence of magnetic field is

$$J_H = n_H e v_H = n_o e v_o (1 + C_1 H^2/p^2) e^{-bH}$$

or $$I_H = I_o (1 + C_1 H^2/p^2) e^{-bH} \tag{5.11}$$

To find the variation in discharge current in the magnetic field, we put

$$\frac{dI_H}{dH} = 0, \quad \frac{bC_1}{P^2}H^2 - \frac{2C_1}{P^2}H + b = 0$$

$$\text{So, } H = \frac{1 \pm \sqrt{1 - \frac{b^2 P^2}{C_1}}}{b} \tag{5.12}$$

As will be shown subsequently that b^2P^2/C_1 is considerably less than one. So we get two values of H at which the discharge current either becomes a maximum or minimum.

$$H' = \frac{2}{b} - \frac{bP^2}{2C_1} \tag{5.13a}$$

and $$H'' = \frac{bP^2}{2C_1} \tag{5.13b}$$

The procedure for calculating the values of b and C_1 from experimental data at different pressures are given in Appendix. From the values of b and C_1, the values of H' and H" have been calculated and entered in Table 5-I.

Table 5-I

Pressure in torr	b	C_1	H' in gauss	H'' in gauss	H_{max} (expt.) in gauss
0.10	5.46×10^{-3}	7.11×10^{-7}	327.90	38.40	405
0.20	4.95×10^{-3}	2.32×10^{-6}	361.30	42.70	410
0.25	5.52×10^{-3}	4.20×10^{-6}	321.20	41.07	402
0.30	6.19×10^{-3}	6.90×10^{-6}	282.70	40.37	400

It is thus seen that the values calculated from 5.13a are in agreement with the values obtained from experimental results to a certain extent; which may be due to the fact that the values of C_1 have been calculated on quantities whose values are to a certain extent uncertain. Further it has been shown by Sen and Das (1973) that the relation $\lambda_H = \lambda_0/(1+C_1H^2/p^2)^{1/2}$ is valid over a certain range of (H/P) values.

Electron temperature in magnetic field:

Since electrons and ions in a transverse magnetic field tend to be separated by Lorentz force, self diffusion will gradually predominate at higher values of H and so far transverse magnetic field H, the self diffusion co-efficient D is considered.

So we have, $D_0 = \frac{1}{3} \lambda_r v_r$

where λ_r is the mean free parth and v_r is the random velocity.

Then $D_H = \frac{1}{3} \lambda_{rH} v_{rH}$

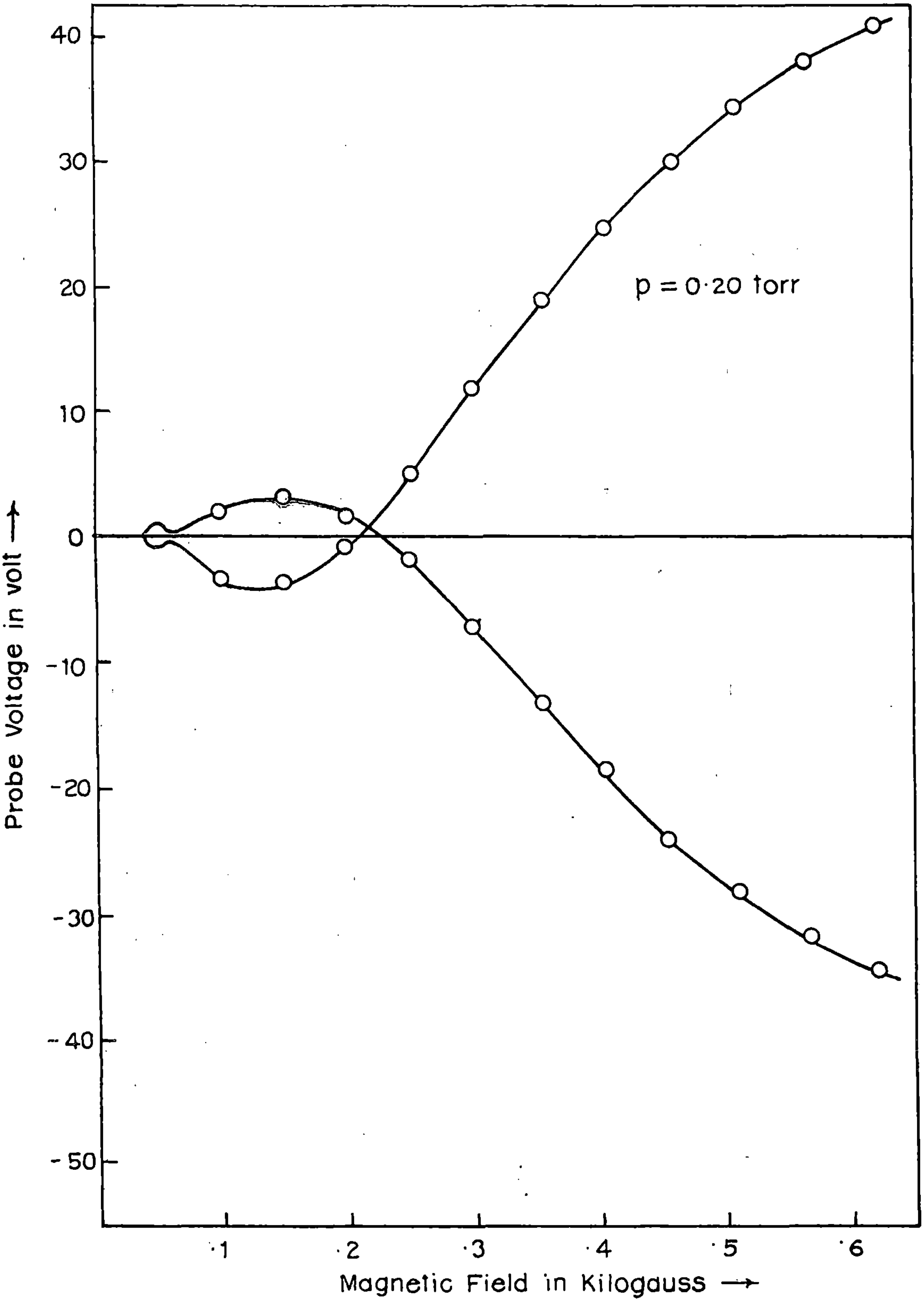
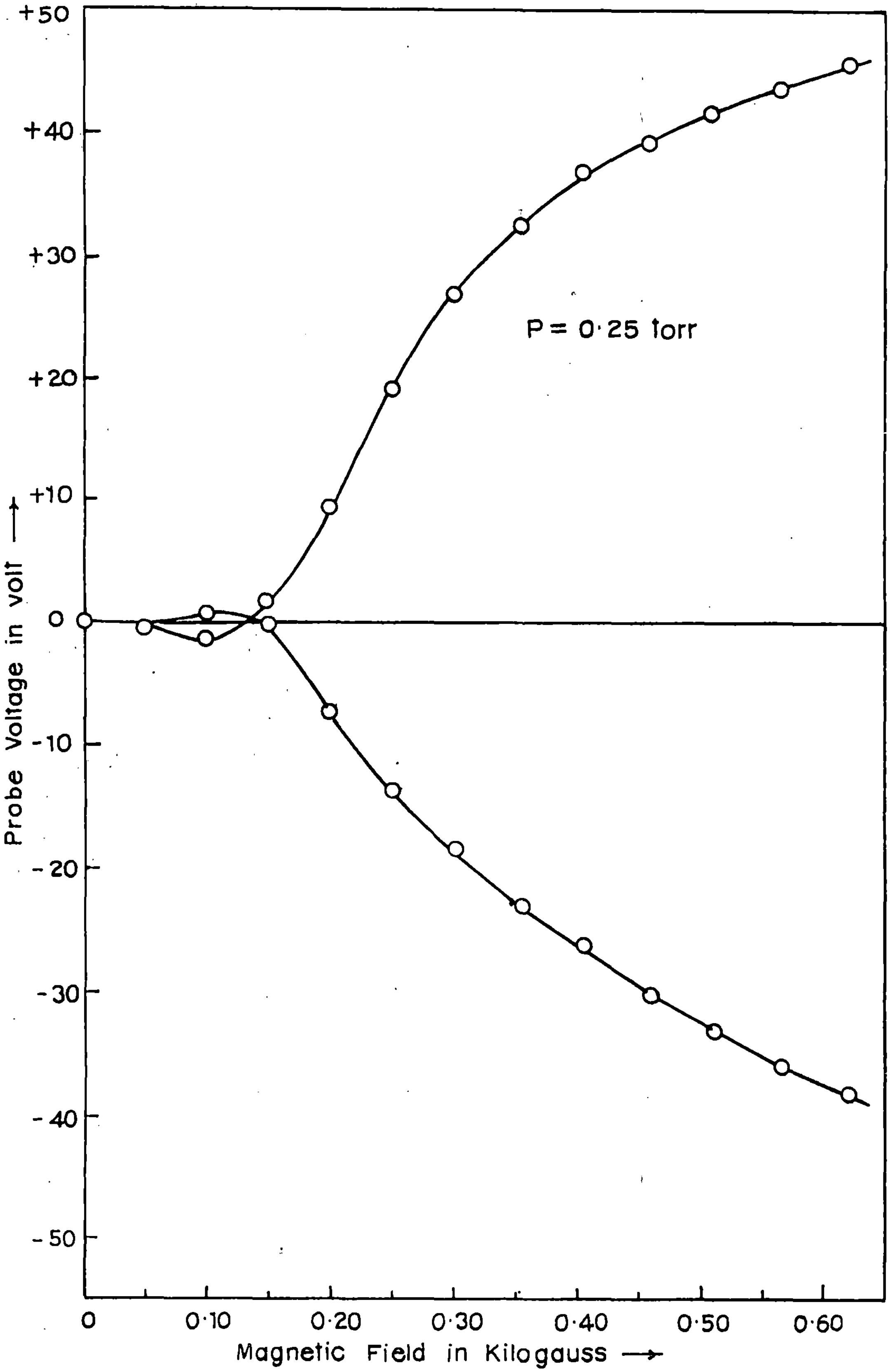

40
30
20
10
0
-10
-20
-30
-40
-50
p = 0·20 torr
Probe Voltage in volt →
·1
·2
·3
·4
·5
·6
Magnetic Field in Kilogauss →

Fig. 5-b


+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
Probe Voltage in volt →
P = 0·25 torr
0
0·10
0·20
0·30
0·40
0·50
0·60
Magnetic Field in Kilogauss →
Fig. 5-C.

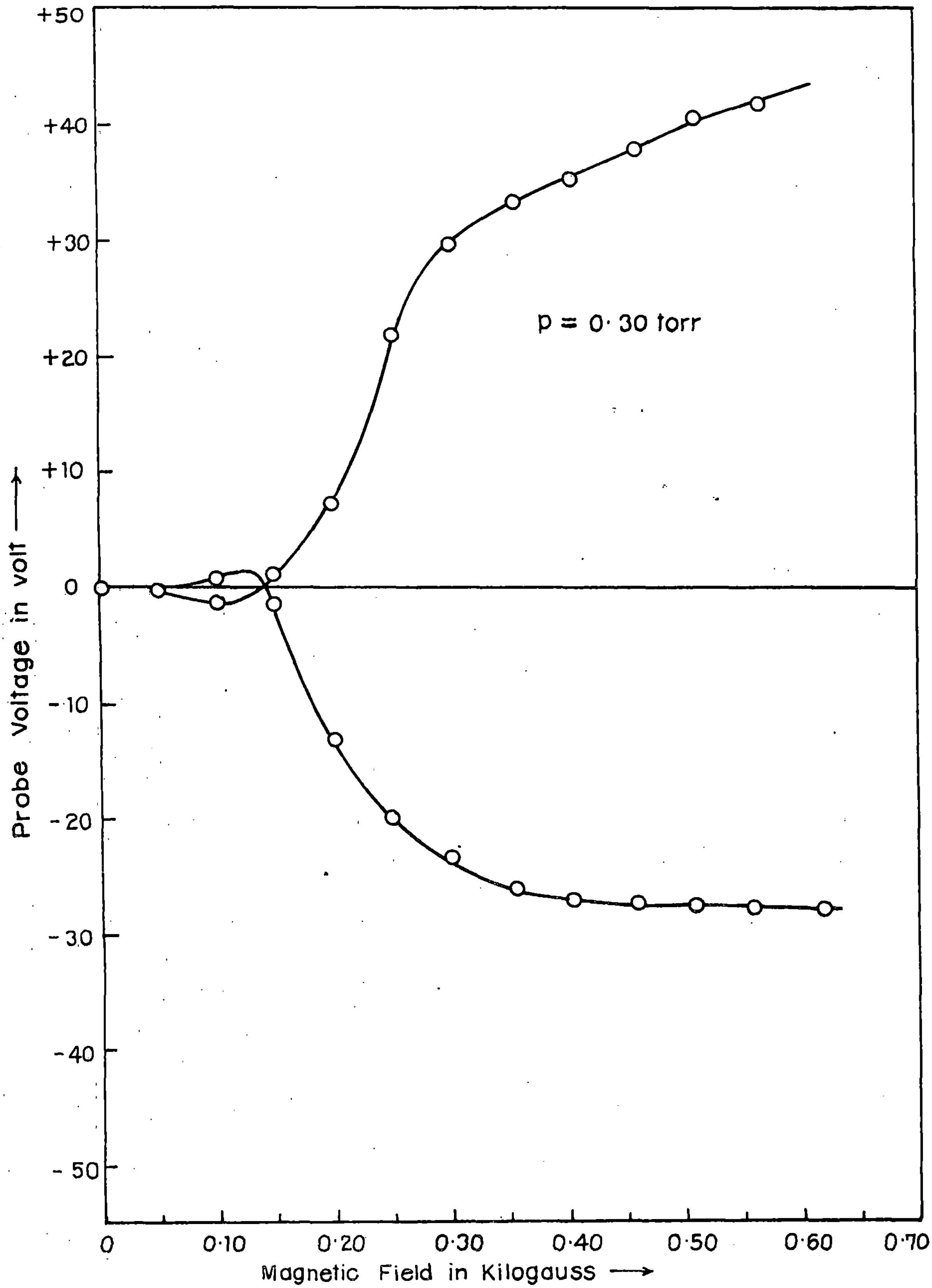

Probe Voltage in volt
Magnetic Field in Kilogauss
p = 0·30 torr
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
0
0·10
0·20
0·30
0·40
0·50
0·60
0·70

Fig. 5-d.

$$\text{So} \quad \frac{D_H}{D_o} = \frac{\lambda_{rH} \cdot v_{rH}}{\lambda_r \cdot v_r}$$

Putting expression for λ_{rH} and D_H, we get $v_{rH} = \dfrac{v_r}{(1 + C_1 H^2/p^2)^{1/2}}$

But $\frac{1}{2} m v_{rH}^2 = k T_{eH} = \frac{1}{2} m v_r^2 / (1 + C_1 \frac{H^2}{p^2}) = \dfrac{k T_{eo}}{(1 + C_1 \frac{H^2}{p^2})}$

Thus when electron self diffusion predominates, then

$$T_{eH} = T_{eo} / (1 + C_1 \frac{H^2}{p^2}) \qquad (5.14)$$

In the 2nd part of the experiment the voltage developed across the two probes one along the axis and other parallel to the axis but away from the axis and adjacent to the wall of the discharge tube has been measured (Table 5-V) over a transverse magnetic field varying from 0.05 to 0.62 kilogauss for pressures 0.20, 0.25 and 0.30 torr. The representative curves are shown in figure 5b, 5c, 5d. In each case it is found that the voltage becomes negative for small values of magnetic field and then becomes positive and rapidly increases with the increase of transverse magnetic field applied in a certain direction. When the field is reversed, the voltage across the probes changes in sign but not in nature, i.e., the voltage across the probes becomes positive for small values of magnetic field and then becomes negative and the negative voltage rapidly increases with magnetic field.

The behaviour of probe voltage should be like that because the transverse magnetic field produces Hall voltage across the probes as a result of charge separation caused by the Lorentz force, but charge separation is opposed [Simon (1955), Longmire (1956), Kaufman (1958)] by the inherent tendency of the plasma which tries to remain electrically neutral by increasing the diffusion in a direction reverse to the direction in which charges moves by Lorentz force.

So when direction of magnetic field is reversed, the sign of probe voltage should change, since the probes remain in the previous geometrical position. The value of probe voltage should have remained same in spite of reversing the magnetic field, but due to the difference in the asymmetry of charge distribution introduced by the reversal of magnetic field with respect to the position of the probes, the value of probe voltage in the two cases have small difference. Thus these two voltages simultaneously appear across the probes and hence voltage measured between the probes is neither a true Hall voltage, nor a true diffusion voltage but a difference between the two voltages is measured between the probes.

So an analytical expression for diffusion voltage and Hall voltage in a transverse magnetic field applied to a plasma, will help us know the expression for the voltage that appears between the probes.

Computation of diffusion voltage in a transverse magnetic field:

We have deduced in the previous section

$$n_H = n_o \left(1 + C_1 \frac{H^2}{p^2}\right)^{1/2}$$

So,
$$\frac{dn_H}{n_H} = \frac{C_1 H/p^2}{1 + C_1 \frac{H^2}{p^2}} \, dH + \frac{dn_o}{n_o} \qquad (5.15)$$

The velocity of diffusion in a transverse magnetic field may be written as

$$V_{DH} = \frac{D_H}{n_H} \frac{dn_H}{dr}$$

If the electric field caused by diffusion along the radial vector of the cylindrical discharge tube be E_H and μ_H is the mobility, then

$$V_{DH} = \mu_H E_H$$

So,
$$E_H dr = \frac{D_H}{\mu_H} \frac{dn_H}{n_H} = \frac{kT_{eH}}{e} \cdot \frac{dn_H}{n_H} = \frac{kT_{eo}/e}{1 + C_1 \frac{H^2}{p^2}} \cdot \frac{dn_H}{n_H}$$

So, diffusion voltage between the probes is given by,

$$\int_0^R E_H \, dr = -V_{DH} = \frac{kT_{eo}}{e} \int_0^H \frac{C_1 H/p^2}{\left(1 + C_1 \frac{H^2}{p^2}\right)^2} dH + \frac{1}{1 + C_1 \frac{H^2}{p^2}} \int_0^R \frac{kT_{eo}}{e} \frac{dn_o}{n_o}$$

Putting the expression for $d\eta_H/\eta_H$ from 5.15

at $r = 0$, $\log J_o = 0$

and at $r \simeq R$, i.e., when the other probe away from the axis is placed close to the wall of the discharge tube, where a sheath of immobile negative charges is formed, and since the electron temperature measures the kinetic energy of the electrons and as the charges are immobile,

$$T_{eo} = 0 \quad \text{at } r = R$$

So under this placement of probes, the 2nd term in 5.16 vanishes. So we have

$$-V_{DH} = \frac{kT_{eo}}{e} \cdot \frac{C_1 H^2/p^2}{1 + C_1 H^2/p^2} \qquad (5.17)$$

Thus 5.17 gives the expression for diffusion voltage in a transverse magnetic field applied to a discharge plasma.

Computation of Hall voltage in case of plasma:

From the equation of motion of charged particles in a magnetic field, we have in a steady state,

$$\left.\begin{aligned} \delta v_x &= -\frac{e\gamma/m}{1+\omega_H^2\gamma^2}\left(E_x - \omega_H \gamma E_y\right) \\ \delta v_y &= -\frac{e\gamma/m}{1+\omega_H^2\gamma^2}\left(E_y + \omega_H \gamma E_x\right) \end{aligned}\right\} \qquad (5.18)$$

If discharge current flows along x-axis, and a magnetic field is applied along z-axis, there will be no current along y-axis in case of a confined plasma.

So, $\delta v_y = 0$, which gives

$$E_y = -\omega_H \tau E_x \qquad (5.19)$$

where E_x is the electric field applied along x-axis and E_y is the field developed to resist any flow of current along y-axis.

So Hall voltage that will appear between the probes whose surfaces are along y-axis and placed at a distance d from each other, will be given by

$$V_H = -\omega_H \tau E_x d \qquad (5.20)$$

$\omega_H = eH/m$ is the cyclotron frequency, and τ is the time of collision of electron with the atom and E_x is the electric field in which the probes are immersed.

But the electrodes in the discharge rube, which are smaller than the diameter of the discharge tube and which are used to provide electric field in the discharge tube, cannot produce uniform electric field from the axis to the periphery of the tube. Rather the field is considerably reduced outside imaginary cylinder enclosed by the electrodes, and on the wall inside the sheath of immobile charges the electric field is practically reduced to zero in the direction of discharge. So one should use mean electric field $\bar{E}_x$ in equation 5.20 in place of E_x. If electric field on the axis is E_x and that on the wall is zero, the mean electric field is given by

$$\bar{E}_x = \frac{1}{2} E_x \tag{5.21}$$

But $$E_x = \frac{E_{xH}}{(1 + C_1 \frac{H^2}{p^2})^{1/2}}$$

where E_{xH} is the true electric field that is present in presence of magnetic field and hence is measurable experimentally when magnetic field is present. Thus we have

$$V_H = -\frac{1}{2}\sqrt{C_1}\,\frac{H}{p}\cdot\frac{E_{xH}}{(1+C_1\frac{H^2}{p^2})^{1/2}}\cdot d \tag{5.22}$$

Thus according to our assumption, the probe voltage is given by

$$V_{pH} = \pm\left[\frac{kT_{eo}}{e}\cdot\frac{C_1 H^2/p^2}{1+C_1\frac{H^2}{p^2}} - \frac{1}{2}\sqrt{C_1}\,\frac{H}{p}\cdot\frac{E_{xH}}{(1+C_1\frac{H^2}{p^2})^{1/2}}\cdot d\right] \tag{5.23a}$$

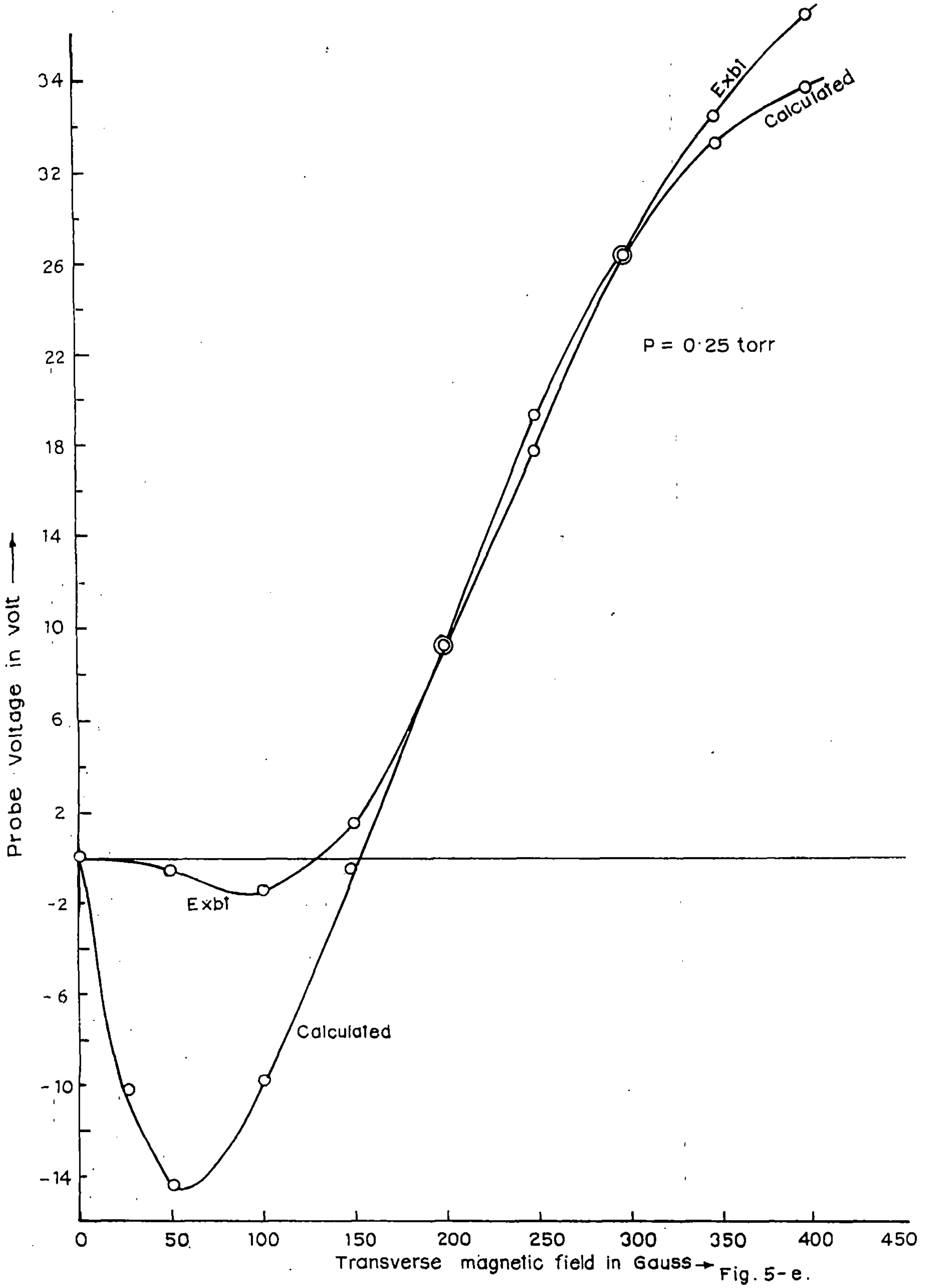
$$V_{pH} = \pm\left[\frac{kT_{eH}}{e}\cdot C_1 H^2/p^2 - \frac{1}{2}\sqrt{C_1}\,\frac{H}{p}\cdot\frac{E_{xH}}{(1+C_1\frac{H^2}{p^2})^{1/2}}\cdot d\right] \tag{5.23b}$$

The expression is expected to give correct probe voltage from a value of transverse magnetic field at which self diffusion of electrons predominates over the ambipolar diffusion and if all the parameters are experimentally measured in a set up for discharge current, pressure and magnetic field. In the present experiment, we have measured E_{xH} and C_1 but not T_{eH}. Equation 5.23a and 5.23b both become identities for H = 0. So except for H = 0, we can measure T_{eH} with the experimental set up described with the help of equation 5.23b. However, we can solve for T_{eo}, using equation 5.23a and then calculate the values of V_{PH} for the other values of H.

Putting d = 1.2 cm for probe separation and other values from table 5-II for H = 200 gauss (for the mean value of H from 0 to 400 gauss) we get kT_{eo}/e =77.66 volt with the help of equation 5.23a.

Then we calculate other values of V_{PH} from 0 to 400 gauss using the values from table 5-II and enter the results of calculation in table 5-III along with the experimental values of V_{PH} and is shown in Fig. 5e.

We thus observe that the nature of variation of the probe voltage when both the diffusion and Hall voltage are taken into consideration is the same as observed experimentally. The quantitative agreement is highly satisfactory for values of magnetic field greater than 150 gauss. The discrepacny observed for low values of magnetic field may be due to the Bohm diffusion process where D_H is propoitional to 1/H instead of $1/H^2$.



34
32
26
22
18
14
10
6
2
-2
-6
-10
-14
0
50
100
150
200
250
300
350
400
450
Probe Voltage in volt
Transverse magnetic field in Gauss
Exbt
Calculated
P = 0·25 torr
Exbt
Calculated

Fig. 5-e.

Table 5 - II

$C_1 = 4.2 \times 10^{-6}$ torr^2/gauss^2 and $p = 0.25$ torr

H in Gauss	0	25	50	100	150	200	250	300	350	400
I_H in mA	13.25	13.30	13.35	13.80	14.55	15.45	16.50	17.85	18.45	18.75
E_{xH} in volt/cm	111.7	111.5	111.3	107.0	100.6	92.9	83.9	72.4	67.3	64.7
Probe voltage in volt (expt.)	0	-0.30	-0.50	-1.50	1.50	9.25	19.25	26.75	32.25	36.50

Table 5-III

p = 0.25 torr (Air)

Magnetic field in Gauss	0	25	50	100	150	200	250	300	350	400
Probe voltage in volt (expt.)	0	-0.30	-0.50	-1.5	1.5	9.25	19.25	26.75	32.25	36.5
Probe voltage in volt (calculated)	0	-10.34	-14.48	-9.75	-0.39	9.25	17.64	26.75	31.00	33.54

Appendix A

Let $x_H = \frac{I_H}{I_o} = \left(1 + C_1 \frac{H^2}{p^2}\right) e^{-bH}$

$$\frac{x_{H_1} e^{bH_1} - 1}{x_{H_2} e^{bH_2} - 1} = \frac{H_1^2}{H_2^2} = \frac{1}{4}$$

if we take $H_2 = 2H_1$ for $P_1 = P_2 = P$

Let, $e^{bH_1} = y$

Hence, $\frac{x_{H_1} y - 1}{x_{H_2} y^2 - 1} = \frac{1}{4}$

Solving the equation for y, we have two values of y given by

$$y_1 = \frac{2x_{H_1} - \sqrt{4x_{H_1} - 3x_{H_2}}}{x_{H_2}}$$

and

$$y_2 = \frac{2x_{H_1} + \sqrt{4x_{H_1}^2 - 3x_{H_2}}}{x_{H_2}}$$

Hence, $b = \frac{\ln y_1}{H_1 \ln e}$ or $b = \frac{\ln y_2}{H_1 \ln e}$

Again, $x_{H_1} e^{bH_1} = 1 + C_1 \frac{H^2}{p^2} = x_{H_1} y$

$$C_1 = \frac{x_{H_1} y_1 - 1}{H_1^2 / p^2} \quad \text{or} \quad C_1 = \frac{x_{H_1} y_2 - 1}{H_1^2 / p^2}$$

Appendix B

For p = 0.20 torr

$b = 4.95 \times 10^{-3}$ and $C_1 = 2.32 \times 10^{-6}$

$$\therefore \frac{b^2 p^2}{C_1} = \frac{4.95^2 \times 10^{-6} \times 4 \times 10^{-2}}{2.32 \times 10^{-6}} = 0.4224$$

So, $\frac{b^2 p^2}{C_1} < 1$

Table 5-IV (Air)

Current through magnet in Amp	Discharge current in mAmp for pressure p in torr (when transverse magnetic field is applied)				
	p = 0.10 torr	p = 0.15 torr	p = 0.20 torr	p = 0.25 torr	p = 0.30 torr
0	4.15	7.50	10.45	13.25	15.35
0.05	4.25	7.55	10.50	13.40	15.55
0.10	4.45	7.85	10.85	13.90	16.00
0.15	4.75	8.35	11.40	14.55	16.65
0.20	5.15	9.05	12.30	15.45	17.35
0.25	5.55	10.05	13.45	16.50	18.10
0.30	6.00	10.95	14.65	17.80	18.95
0.35	6.55	12.10	15.55	18.55	19.60
0.40	7.05	12.75	16.05	18.75	19.90
0.45	7.45	12.75	16.10	18.70	19.80
0.50	7.65	12.45	15.90	18.40	19.55
0.55	7.70	12.10	15.50	18.00	19.05
0.60	7.55	11.65	15.10	17.40	18.55
0.65	7.25	11.25	14.70	16.90	18.10
0.70	6.95	10.80	14.25	16.50	17.70
0.75	6.75	10.30	13.80	16.15	17.30
0.80	6.40	9.90	13.45	15.80	16.90
0.85	6.05	9.45	13.05	15.40	16.50
0.90	5.80	9.10	12.75	15.00	16.10

Table 5 - V (Air)

Current through the magnet in Amp	Probe Voltage in Volt for pressures p in torr					
	p = 0.20 torr		p = 0.25 torr		p = 0.30 torr	
	Magnet Field Forward	Magnetic Field reversed	Magnet Field Forward	Magnetic Field Reversed	Magnetic Field Forward	Magnetic Filed Reversed
0	0	0	0	0	0	0
0.05	-0.2	+0.1	-0.5	+0.1	-0.4	+0.1
0.10	-3.4	+2.0	-1.4	+0.6	-1.4	+0.8
0.15	-3.7	+3.2	+1.6	-0.4	+1.0	-1.5
0.20	-0.7	+1.7	+9.1	-7.2	+7.7	-13.0
0.25	+5.0	-1.7	+19.2	-13.5	+21.2	-19.9
0.30	+11.7	-7.2	+26.7	-18.6	+29.5	-23.5
0.35	+19.0	-13.0	+32.5	-22.8	+33.1	-26.0
0.40	+24.8	-18.5	+36.7	-26.1	+35.5	-27.0
0.45	+30.0	-24.0	+39.5	-29.9	+38.0	-27.3
0.50	+34.5	-28.0	+41.6	-33.0	+40.1	-27.3
0.55	+38.0	-31.7	+43.6	-36.0	+42.0	-27.5
0.60	+40.9	-34.4	+45.7	-37.5	+43.8	-27.8

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