CHAPTER - II.

SCOPE AND SUMMARY OF THE PRESENT WORK.

SCOPE OF THE PRESENT WORK.

In the present investigation the following problems in the electrical discharge phenomena have been investigated.

(a) Plasma parameters from radiofrequency conductivity measurements.

(b) Mobility and diffusion of electrons in magnetic field.

(c) Variation of discharge current in a magnetic field.

(d) Spectral line Intensities in Glow discharge in a transverse magnetic field.

(e) Variation of Townsend's second coefficient with $(E/_p)$ and magnetic field and breakdown of gases in a transverse magnetic field.

(a) Plasma parameters from radiofrequency conductivity measurements.

The problem of radiofrequency conductivity of ionised gases has been investigated by Childs (1932), Appleton and Chapman (1935) and also by Imam and Khastgir (1937). Margenau (1946) investigated theoretically the conductivity of ionised gases specially for frequencies in the microwave region taking into consideration the Maxwell Boltzman distribution law for electron velocities. Similarly the problem of radiofrequency conductivity in presence of transverse magnetic field was investigated by Appleton and Boohariwalla (1935) and also by Gilardini (1959).

The method is useful due to the fact that from the radiofrequency conductivity measurements it is possible to calculate the plasma parameters such as collision frequency, electron density electron temperature, Debye shielding distance and the dielectric constant of the plasma. A precise knowledge of these parameters, their variation with pressure, discharge current and magnetic field is essential for the proper understanding of the mechanism operating in the discharge. Though there have been some measurements of these parameters in the microwave region the corresponding data in the radiofrequency range has been comparatively little reported. An alternative method has been developed in this laboratory for the measurement of radiofrequency conductivity and measurements have been made in case of helium, neon, argon, hydrogen, air and carbondioxide and the plasma parameters and their variation with pressure discharge current and magnetic field have been studied.

(b) Mobility and diffusion of electrons in magnetic field.

The determination of mobility and diffusion coefficient and the nature of their variation in a magnetic field is essential for the theoretical computation of breakdown voltage in gases in radiofrequency and microwave region under a transverse magnetic field and for understanding the nature of the processes occuring during the breakdown. Though there have been a good deal of measurements of the mobility coefficient for a wide range of $(E/_p)$ values in different gases the corresponding measurements in presence of magnetic field has been little reported so far. Townsend and Gill (1938) showed from theoretical consideration that the mobility coefficient of electrons in the direction of the magnetic field is reduced and is given by

$$\mu_H = \frac{\mu}{1 + \omega_b^2 \tau^2} \quad \text{where} \quad \omega_b = eH/m \quad \text{and} \quad \tau$$

is the time between the successive collisions. The mobility coefficient in presence of magnetic field has been determined in case of helium, neon, argon and hydrogen from breakdown measurements in presence of magnetic field and also from radiofrequency conductivity measurements and the validity of Townsend and Gill's expression has been examined. This provides us with the range of $(H/_p)$ values over which the equation is valid.

The diffusion coefficient of electrons in presence of magnetic field has been calculted from the measured d.c. conductivity of the gases. The problem whether the diffusion coeficient of electrons in a direction perpendicular to magnetic field varies inversely as H^2 as suggested by Townsend and Gill (1938) or inversely as H as predicted by Massey and Williams (1949) has been tested in the present investigation.

The results obtained have been utilized for calculating theoretically the breakdown voltages in gases in presence of magnetic field.

(c) Variation of discharge current in a transverse magnetic field in a glow discharge.

When a magnetic field acts upon a glow discharge various changes such as increase of equivalent pressure, decrease in the length of cathode dark space, a change in radial ion density and a marked change in the voltage current characteristics of the discharge take place. Theoretical interpretation of these phenomena have been provided by Townsend (1938), Guntherschulge (1924) and also by Allis and Allen (1937). Most of the experimental work in this field has been done in a longitudinal magnetic field. The effect of a transverse magnetic field on the positive column as regards the electron temperature, electric field gradient and the new electron density has been theoretically calculated by Beckman (1948). Though there have been some measurements as regards voltage current characteristics in a discharge in a transverse magnetic field no theoretical interpretation has been provided and it is worth while to undertake a systematic investigation regarding the variation of discharge current in a variable transverse magnetic field and since the discharge current is a function of radial electron density and axial electric field, the present investigations are expected to show how these parameters are influenced by a transverse magnetic field. The experimental data will also provide a verification of the theory provided by Beckman (1948). The present investigation provides experimental data in case of air, carbondioxide, helium, neon and hydrogen and a theoretical interpretation has been sought to be provided.

(d) Spectral line Intensities in Glow discharge in a transverse magnetic field.

Some amount of work regarding the variation of spectral line intensities in a glow discharge with regard to variation of discharge current, the pressure of the enclosed gas have been studied by Rossler and Schonherr (1938), Fowler and Duffendack (1949). Besides the above parameters the effect of an external magnetic field on the intensity of spectral line has been studied by Rokhlin (1939) and by Fabrikant and Rokhlin (1938, 1939) in case of mercury vapour discharge. With increasing magnetic field, the intensity in case of Hg. line $\lambda = 5791$ Å and $\lambda = 3905$ Å gradually increases and attaining a maximum value gradually falls. Kulkarni (1944) also made similar observations in case of constricted discharge in hydrogen. No theoretical explanation of the phenomena was however provided. In order to understand more clearly the behaviour of fast electrons having energy greater than the excitation energy of the gas it is proposed to make a systematic observation of the intensity distribution of the spectral lines in the glow discharge in gases like hydrogen, helium and mercury vapour in presence of a variable transverse magnetic field.

(e) <u>Variation of Townsend's second coefficient with $(E/_p)$ and magnetic field and breakdown of gases in transverse magnetic field.</u>

The variation of Townsend's second coefficient with $(E/_p)$ where E is the breakdown voltage per unit length and P is the pressure has been studied by a large number of investigators in various gases. A systematic investigation of the problem was undertaken by Sen and Ghosh (1962) in case of air in case of electrodeless discharge and a theoretical equation was developed taking into consideration the various secondary processes occuring in the discharge. In order to extend the theory in case other gases and also to verify the validity of the theory over a wide range of $(E/_p)$ values the present investigation has been undertaken. To find the effect of internal electrode measurements have also been mode with discharge tubes fitted with electrodes. The investigation reports the results in case of helium, neon and argon.

The general effect of magnetic field on the discharge phenomena has been shown by Townsend and Gill (1938) as well as by Blevin and Haydon (1958) is to change the pressure P to an effective value of pressure given by $P_e = P\,(1+C_1\,H^2/P^2)^{1/2}$ where

$C_1 = (eL/mv)^2$ where L is the mean free path of the electron in the gas at a pressure of 1 mm. of Hg. and v_r is the random velocity of the electron. As γ is a function of (E/p) it is natural to suppose that γ will change in presence of magnetic field and the nature of the change has been investigated in case of all the three gases and an attempt has been made to present a theory which can explain the observed results.

In calculating theoretically the breakdown voltage in case of gases under the action of crossed electric and magnetic field the variation of (α/p) with magnetic field has been taken into consideration by the previous workers. As γ is also a function of the magnetic field its variation should also be taken into consideration and a detailed theory has been put forward by Sen and Ghosh (1962) regarding breakdown of gases in crossed electric and magnetic field. The present work is an extension of the theory developed by Sen and Ghosh in case of helium, neon and argon.

The breakdown measurements have been extended up to radiofrequency region in case of these three gases and in presence of a transverse magnetic field. All previous determinations such as those of Thomson (1940), Hale (1946) were performed in a resonance magnetic field where the relation $f_{applied} = eH/mc$ was satisfied. Brown and his associates (1948) extended the measuremnts up to microwave region. The object of the present investigation is the study the nature of variation of breakdown voltage in a non resonant magnetic field where the frequency of excitation is far removed from the resonant value. A detailed theory has been put forward by Sen and Ghosh (1963) utilising Kihara's theory (1952) of radiofrequency breakdown in which the effect of magnetic field has been suitably introduced. The present work is the application of the theory in case of breakdown in helium, argon and neon.

With these objects in view the present investigations have been undertaken.

SUMMARY OF THE PRESENT WORK.

Plasma Parameters from Radiofrequency Conductivity measurements.

Radiofrequency conductivity measurements have been made in the case of ionised gases such as argon, helium, neon, air, hydrogen and carbondioxide over the pressure range of a few microns to 700 microns and under an external magnetic field varying from 0 to 550 gauss. From the experimentally determined values of σ_r the real part of conductivity it has been possible to calculate the electron density, the collision frequency and electron temperature and study their variation with pressure, the discharge current and the magnetic field. A quantitative theory has been proposed to explain the variation of electron temperature with magnetic field and the experimental data compare well with the theoretical variation specially for low values of pressure and the magnetic field. The pressure $(P_H)_{max}$ at which the r.f. conductivity becomes maximum shifts to higher values with the increase of the magnetic field for all the gases studied. Good quantitative agreement with the values of $(P_H)_{max}$ derived on the basis of the concept of equivalent pressure and the variation of random velocity with the magnetic field and the experimental values is observed. The dielectric constant and the Debye shielding distance have been obtained from values of σ_r and their variation with magnetic field and pressure has been studied. A qualitative explanation of the variation of these two parameters has been suggested.

Mobility and Diffusion of electrons in magnetic field.

The values of mobility coefficients of electrons in ionised gases such as helium, neon, argon and hydrogen in presence of a transverse magnetic field varying from 0 to 200 gauss and over a wide range of pressure have been computed from

(a) breakdown voltage measurements and from (b) radiofrequency conductivity measurentnts. The validity of the expression $\mu/\mu_H = 1 + C_1 H^2/p^2$ deduced by Townsend and Gill (1938) and also by Blevin and Haydon (1958) has been tested by plotting μ/μ_H against $1/p^2$ and the curve is a straight line for a limited range of pressure above .125 mm. of Hg. The constant C_1 is found to decrease with the increase of the magnetic field and the variation of C_1 against H is parabolic in nature. An analytical expression has been deduced which explains the variation to a first approximation.

The variation of diffusion coefficient of electrons in a variable transverse magnetic field has been studied at a fixed pressure in case of neon, helium, hydrogen carbondioxide and air by measuring the conductivity of the ionised gas. It has been noted that within the limits of measurements ($H < 100$ gauss) the normal diffusion theory of Townsend holds and the variation of D/D_H against H^2 is a straight line. The value of the constant C_1 is however a function of the magnetic field and a similar theoretical expression for C_1 as deduced in case of electron mobility holds in this case also. No anomalous diffusion of electrons within the range of (H/p) values used in the investigation has been observed.

<u>Variation of discharge current in a transverse magnetic field in a glow discharge.</u>

The variation of discharge current in a transverse magnetic field (0 - 300 gauss) has been studied in the positive column of a glow discharge in air, carbondioxide, hydrogen,argon and neon within the pressure range of 80 to 200 millitorr.The current gradually rises with the increase of the magnetic field then attains a maximum value 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 and the maximum value of the current is inversely proportional to pressure in case of all the gases. Utilizing Beckman's expression (1948) for axial electric field and the radial electron density distribution in a transverse magnetic field a mathematical expression for the discharge current and its variation with the magnetic field has been deduced. The theoretical results are in qualitative agreement with experimental observations and the causes of discrepancy have been attributed to (a) limitations of Beckman's expression for electron density distribution and axial electric field and (b) absence of data for fraction of energy loss in collision and the electron temperature at $(E/_p)$ values at which the present observations have been made.

Spectral line intensities in Glow discharge in a transverse magnetic field.

The relative intensities with an without magnetic field of some of the spectral lines from the positive column of glow discharge in hydrogen, helium and mercury vapour excited by a radiofrequency source have been measured in a transverse magnetic field varying from 0 to 3000 gauss. The intensity in each case increases gradually with the increase of the magnetic field and attaining a maximum at a particular value of the magnetic field which is different for different spectral lines gradually diminishes. A quantitative theory has been provided taking into consideration the increase of equivalent pressure and decrease of electron temperature due to the presence of the magnetic field. The value of the magnetic field at which the intensity becomes a maximum as well as the maximum intensity ratio has been calculated. The experimental results are in fair agreement with theoretical deductions and the causes of discrepancy have been discussed.

Variation of Townsend's second coefficient with $(E/_p)$.

The values of γ the Townsend's second coefficient have been calculated from breakdown measurements over a wide range of $(E/_p)$ values for argon, helium and neon with different lengths of discharge tube in case of electrodeless as well as in case of discharge with electrodes. The variation of γ with $(E/_p)$ shows that is large both for high and low values of $(E/_p)$ and remains constant for a certain range of $(E/_p)$ values near the value for minimum breakdown voltage. The theory proposed by Sen and Ghosh (1962) has been applied in this case also and it has been found that contributions to γ arise from four distinct causes (a) electrons striking the glass surface or the electrodes in case of discharge with electrodes (b) positive ions striking theglass surface (c) ionization by positive ions (d) photo ionization. The mathematical expression derived by Sen and Ghosh (1962) can explain the variation of γ with $(E/_p)$ in case of these gases also.

Variation of Townsend's second coefficient in crossed Electric and Magnetic fields.

From the measurements of breakdown voltages in a transverse magnetic field the values of γ_H , Townsend's second coefficient in a magnetic field have been calculated in case of argon, helium and neon and the variation of γ_H against H has been found to be hyperbolic in nature for different values of pressure such as 50μ , 60μ , 75μ , 150μ , 180μ and 220μ , the magnetic field varying from 0 to 60 gauss. Assuming the expression derived by Sen and Ghosh (1962)

$$\gamma = A' \frac{E}{P} + \frac{B'}{E/P} + C'$$

an expression has been deduced for the variation of γ_H with magnetic field. The formula deduced can explain the variaion of γ_H with magnetic field and the quantitative agreement is also satisfactory . The limitations of the theoretical derivation have been discussed.

Breakdown of Gases in crossed Electric and Magnetic fields.

The variation of breakdown potential in case of argon, helium and neon has been studied in case of electrodeless discharge in a discharge tube of length 11 cm. and in case of discharge with electrodes in a discharge tube of length 18 cm. in a transverse magnetic field varying from 0 to 200 gauss. The breakdown voltage is always found to be higher than when no magnetic field is present for all values of pressure and the pressure at which the breakdown voltage becomes a minimum increases gradually as the magnetic field is increased. Incorporating the concept of equivalent pressure (Blevin and Haydon, 1958) as well as the variation of γ with H (Sen and Ghosh, 1962) an expression for breakdown voltage in crossed electric and magnetic field has been deduced. The new expression can not only explain the increase of breakdown voltage in a magnetic field but can account satisfactorily the shift of pressure for minimum breakdown voltage as the value of the magnetic field is gradually increased.

Breakdown of Gases in a Radiofrequency Field in Presence of a Transverse Magnetic Field.

Breakdown characteristics of a gas (helium, neon and argon) under r.f. excitation (frequency 4-12 Megacycles/sec) in a transverse nonresonant magnetic field (0-120 gauss) have been studied over a pressure range of a few microns to 1.5 mm. of mercury. The breakdown voltage has been found to be greater than when no magnetic field is present for all values of pressure and the pressure at which the breakdown voltage becomes minimum increases with the increase of the magnetic field. The experimental results indicate that major diffusion and mobility losses take place along the axis in which the electric field is applied. The theory developed by Sen and Ghosh (1965) can explain satisfactorily the increase of breakdown voltage as well as the shift of pressure for minimum breakdown voltage specially for low values of magnetic field. The discrepancy with experimental results for higher values of magnetic field has been attributed to (a) uncertainty in the values of molecular constants introduced by Kihara in his theory (1952) (b) inadequacy of the equivalent pressure concept at high $(H/_p)$ values.