

CHAPTER - II.

SCOPE AND OBJECT OF THE PRESENT WORK

SUMMARY OF THE PRESENT WORK

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Though the various aspects of the phenomena of electrical discharge have been explained by the existing theories there are certain problems which require more exhaustive theoretical and experimental treatment and the present work undertakes to investigate some of these problems.

(a) BREAKDOWN OF GASES BY A RADIOFREQUENCY ELECTRIC FIELD.

The condition for the breakdown of a gas excited by high frequency electromagnetic waves depends mainly upon factors such as the pressure of the gas, the dimension of the discharge tube and the frequency of excitation. The two dominant factors by which electrons are lost are diffusion and mobility and if the gas is an electron attaching one, then by electron attachment also. The electrons are assumed to be produced mainly by ionization collision. Based on these assumptions Herlin & Brown (1947) developed the theory of high frequency breakdown where the dominant cause for electron removal process is diffusion. Starting from a molecular model and assuming suitable crosssections for ionization and excitation processes Kihara (1952) has developed a phenomenological theory of electrical discharge phenomena. In his theory he has assumed both diffusion and mobility as electron removal processes. In order to ascertain which process is dominant under certain conditions as the cause of electron removing process it is necessary to carry out experiments with discharge tubes of different dimensions and the pressure varying within wide limits. Consequently breakdown experiments have been performed with discharge tubes of different dimensions while the pressure is varied from a few microns of Hg. to a few millimeters of Hg. and with different frequencies of excitation. It will also be of interest to see whether the experimental results can be explained by Kihara's theory because no systematic experimental verification of the theory has so far been carried out. Electron attachment is also another process by which electrons are lost in electron attaching gases and this factor has to be incorporated in the general equation of breakdown. Attempt will be made to take into consideration the

effect of attachment and to see whether the experimental results support the modified theory.

The breakdown of a gas excited by a radiofrequency voltage in presence of a transverse magnetic field has been studied by previous workers and theoretical interpretation of the experimental results has been advanced. Both longitudinal and transverse magnetic fields have been used and the frequency of excitation and the value of the magnetic field have been adjusted in such a way that the relation $\omega = eH/mc$ is satisfied where ω is the frequency of the applied field and eH/mc is the cyclotron frequency. It will be of interest to see how the breakdown voltage as well as the pressure at which the breakdown voltage becomes a minimum change when the magnetic field is far removed from the resonance value. The procedure to adopt in such a case is to modify the breakdown equation taking into account the effect of magnetic field. It is proposed to carry out such calculation in case of both Brown's and Kihara's theory and verify the theoretical deductions with the experimental observations. This study is expected to give us information regarding the interaction of the magnetic field with ionised gases.

(b) GAS BREAKDOWN IN A RADIOFREQUENCY FIELD IN PRESENCE OF A SUPERIMPOSED D.C. FIELD.

It was observed by Verela (1947) and Kirchner (1947) that the breakdown potential of a gas excited by a radiofrequency field increased when a d.c. field is superimposed across the discharge tube. It was expected however that the presence of the d.c. field would hasten ionisation and a smaller breakdown voltage would be necessary, but the results were contrary to what was expected. Vernarin and Brown (1950) calculated theoretically the distribution function of electrons in an ionised gas in presence of both radiofrequency and d.c. fields and they suggested that when the radiofrequency field is only present, the

electrons are lost mainly by^d diffusion but when in addition a d.c. field is applied the electrons are lost by mobility also. This increase in loss can be compensated by the increase in generation of electrons and consequently the value of the radiofrequency breakdown voltage increases. The theory was verified by^{Varnesim and} Brown (1950) in case of air at a pressure 38 mm. of Hg. where a d.c. field upto 200 volts/cm was applied. No systematic study of the breakdown of gases under the simultaneous action of the a.c. and d.c. fields have so far been made and it is expected that this study will throw more light in the mechanism of breakdown. As Kihara's theory (1952) is a general one it will be interesting to see how the theory can be further modified by taking into consideration the increased loss due to mobility and to corroborate it with the findings of the experimental results. Further^{a e} Varnesim and Brown (1950) in deducing their theory only considered the effects of increased loss due to mobility and diffusion but did not take into account the contribution made by increased ionization due to d.c. field. This factor may be small when the applied d.c. field is small but it has to be taken into consideration when the d.c. field becomes comparable with the radiofrequency voltage applied. Consequently the general theory has to be modified by taking into consideration this increase in the electron generation process and it is expected that at a certain value of the d.c. field the breakdown voltage will show a maximum and with the further increase of the applied d.c. voltage, the radiofrequency breakdown voltage will show a decrease, because at higher d.c. voltages ionization by the d.c. field will be considerable. The object of this part of the work is thus to see whether the breakdown phenomena will follow this process and whether the experimental results agree^r with the theory developed. The study of the effect of attachment in this type of gas breakdown in some electron attaching gases will also be studied.

(c) SECONDARY ELECTRON RESONANCE BREAKDOWN MECHANISM

The theory of mechanism of breakdown of a gas at pressures less than a few microns and excited by a radiofrequency field has been provided by Gill and Von Engel (1948) and Hatch and Williams (1953, 1954). It has now been established that breakdown is caused by the increase of electron by the resonance of secondary electrons with the electric field. A few electrons present initially by natural causes were accelerated to one end electrode where they produced secondary electrons by impact. These secondaries were emitted in a reverse electric field which carried them to the opposite electrode in approximately half a cycle to produce another group of secondaries. If secondary emission yield is greater than unity, electrons are multiplied to a very large quantity in a very short duration and this results in a breakdown of the gas. Hatch and Williams extended the theory by assuming higher modes besides the conventional half cycle one. The theory of Gill and Von Engel predicts an cut off law relating out off frequency and electrode separation. Though the above theory can explain most of the experimental observations, it is worth while to investigate some of the consequences of the theory with regard to variation of starting voltage and the out off frequency with the length of the discharge tube.

The effect of super imposing an external field upon this type of discharge was investigated by Kossel and Krebs (1954) but no quantitative explanation of the observed results was provided. It has been found that superimposing a d.c. field parallel to high frequency field starting can be made more difficult. A small static magnetic field perpendicular to high frequency electric field causes a general increase in breakdown potential and a lowering of the cut off frequency without changing the nature of the $(E - \lambda)$ curve where E is the starting field and λ is the wavelength of the radiofrequency field. Deb and Goswami (1964) made a theoretical approach to the problem when a steady magnetic field is placed perpendicular to the high frequency field.

No systematic observation of the phenomena of the secondary electron resonance under the action of an external magnetic field has so far been undertaken. The object of this part of investigation is to study the effect of a transverse magnetic field on the breakdown potential in discharges controlled by the phenomena of secondary electron resonance and also the effect it produces on the cut off frequency. It is evident that the theory of the previous workers has to be modified to take into consideration the effects produced by the magnetic field and it is presumed that these investigations may throw some light on the mechanism of such discharge.

(d) LIGHT INTENSITY OF GLOWDISCHARGES IN A STEADY MAGNETIC FIELD.

The radiation property of glow discharges excited by d.c. electric field has been studied previously and the different processes contributing to the intensity have been identified. Rossler and Schonherr (1936) identified both pressure and current dependent losses of the radiation of Hg. ($6^3 P_1 - 6^1 S_0$) and attributed them to the collisions of the second kind with neutrals and electrons respectively. Fowler and Duffendeck (1949) found the dependence of the intensity of spectral lines upon the tube current and observed that the variation is linear within the experimental error for all types of transitions and over a current range of half a milliamp. to one hundred milli ampere. The effect of an external magnetic field on the intensity of glow discharge was studied by Rokhlin (1939) who observed maxima of some of the resonance lines of mercury vapour by applying a longitudinal magnetic field. Kulkarni (1944) studied discharges in some gases, including some rare gases in a transverse magnetic field and found that the intensity of some of the lines shows a maximum at different magnetic field intensity and the magnetic field at which the maxima occurs depends upon the wavelength and the presence of the foreign gas. No mathematical theory was however presented to explain quantitatively the observed experimental results. Though the factors which contribute to the line intensity in a glow discharge have been identified, yet no

systematic theory has so far been developed to explain how the intensity will change when the pressure or the tube current changes or an external perturbing force is superimposed upon the glow discharge. The nature of the exciting field to produce the glow discharge has also not been investigated systematically . Beck (1935) however in the point to point comparison found steady glow discharge in mercury indistinguishable from a 100 Mc/sec discharge and the nature of the radiation property was also found to be identical.

In view of the above consideration it has been decided to study the intensity of lines in glow discharge in various gases when the exciting field is either a d.c. source or a Radiofrequency one. The influence of a transverse magnetic field on the intensity of the lines will be studied and an attempt will be made to develop a theory which can explain the experimental observation. The study is important not only to explain how external perturbing forces affect the factors contributing to intensity but will also help in better understanding of the processes involved in the emission and absorption of spectral lines.

In the present scheme of work, the above problems will be studied experimentally and attempt will be made to advance theories which can explain the observed experimental facts. The subject of Electrical discharge phenomena is receiving more attention now a days because of the availability of new experimental techniques with which it can be investigated and also because it provides basic data for the science of Plasma Physics.

SUMMARY OF THE PRESENT WORK.

- A. DIELECTRIC BREAKDOWN OF GASES BY RADIOFREQUENCY UNIFORM FIELD (ELECTRICAL)
 (a) WITHOUT SUPERIMPOSED MAGNETIC FIELD (b) WITH NON-RESONANT EXTERNAL
 d.c. MAGNETIC FIELD TRANVERSE TO ELECTRIC FIELD.

The work has been done in two parts at two different pressure ranges and with different gases as dielectric medium. In the first part measurements of breakdown voltages have been carried out in molecular in gases such as hydrogen, air, oxygen and carboni-oxide at pressures varying from 1 m.m. to 6 m.m. of mercury, ^u Under the excitation of a radiofrequency voltage of frequency 17.6 Mc/sec. The length of the discharge tube is 0.4 cm. and radius 1.4 cm. Measurements have been taken in presence of a ^t transverse magnetic field varying from zero to 1800 gauss. It has been observed that if (E/P) is plotted against " $P\Lambda$ " where "E" is the breakdown voltage per cm., "P" the pressure and " Λ " the diffusion length, then (E/P) gradually decreases with increasing values of " $P\Lambda$ " for all the gases studied. The experimental conditions indicate that electrons are lost by diffusion and the results have been sought to be explained by the theories of Herlin and Brown (1947) and ⁸ Kihara (1952) after modification due to the effects produced by electron attachment and magnetic field. The theoretical expressions thus deduced can explain the observed results quantitatively for low values of magnetic field and high pressure and the expressions deduced from Herlin and Brown's theory are in better agreement with experimental results than those deduced from Kihara's theory. At higher magnetic fields there is divergence between the theoretical and experimental results which has been attributed to the inadequacy of the equivalent pressure concept at high (H/P) values where H is the magnetic field and also to the uncertainty in the values of molecular constants introduced by Kihara in his theory.

In the second part of the work, the pressure range lies between a few microns to 1.5 mm. of mercury and some rare gases such as helium, neon and argon have been used. Steady d.c. magnetic field placed transverse to high frequency electric field (frequency lies between 4 Mc/sec to 12 Mc/sec) is varied from zero to 120 gauss. The discharge tube length is 10 cm. and the radius of the electrode is 5 cm. 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 the major diffusion and mobility losses take place along the axis ⁱⁿ which the electric field is applied. The theory of Kihara (1952) regarding the breakdown of a gas when it is excited by radiofrequency voltage, ascribed the loss of electrons to diffusion and mobility and Sen and Ghosh (1963) modified this theory by the introduction of the effects due to the magnetic field and deduced a new expression for the breakdown voltage and also the pressure at which the breakdown voltage becomes minimum. This work has been undertaken to supplement the verification of this theory and extend it to the case of rare gases under identical conditions of breakdown in a nonresonant transverse magnetic field. In order to conform with the experimental set up, three dimensional treatment of the problem has been carried out but it is observed that one dimensional treatment shows better agreement with the experimental results. The discrepancy with the experimental results for higher values of magnetic field has been attributed to the identical causes as in the earlier experiment.

B. DIELECTRIC BREAKDOWN OF GASES BY RADIOFREQUENCY ELECTRIC FIELD IN THE PRESENCE OF PARALLEL SUPERIMPOSED d.c. FIELD.

Results of high frequency (10 Mc/sec.) breakdown voltage with superimposed d.c. electric field have been obtained ^{for} helium, neon argon and the molecular

gas oxygen, keeping the pressure of the gas constant at 10mm of mercury. The variation of applied d.c. voltage along the length of the tube is from zero volts/cm to 70 volts/cm . It is found in all the cases studied that the high frequency breakdown voltage is higher when both the fields are present than when the gases are excited by the radiofrequency field alone and the breakdown voltage gradually increases with the increase of the applied d.c. field. The variation of breakdown field with d.c. field is of the same nature in all of the gases studied. A theoretical expression for the breakdown voltage in presence of both r.f. and d.c. fields has been deduced from the theory of electrical discharge by Kihara (1952) together with the expression of equivalent length as deduced by Varnerin and Brown (1950). The theoretical expression could not explain satisfactorily the experimental results, and the rate of rise of breakdown voltage in the d.c. field as obtained from theory is smaller than that obtained from the experimental results. The discrepancy has been ascribed partly to the uncertainty in the values of the numerical constants introduced by Kihara (1952) and also to the increase of diffusion caused by the presence of positive ions—a factor which has not been taken into consideration in this treatment.

This work has been further extended by measuring the breakdown voltage in molecular gases like air, hydrogen, oxygen and carbon-di-oxide at different pressures with the d.c. field ^ω varying from zero to 240 volts/cm. Like the earlier part of this work, here also it is found that the breakdown voltage increases when d.c. field is small and when the field is further increased it shows a maximum and then gradually falls for all the gases studied, the maximum occurring at a d.c. voltage which is different for different gases and is also different for different pressures. It has been shown that, when the d.c. field is small, the dominant factor is the loss of electrons by diffusion as well as by mobility which causes the breakdown voltage to increase, but when the d.c. field is increased, contribution due to d.c.

ionisation has also to be taken into consideration. This d.c. ionisation α contributes to total ionisation S and causes a decrease in the radiofrequency voltage necessary for breakdown. A mathematical expression has been deduced which explains satisfactorily the observed experimental results. In the expression deduced the effect of secondary ionisation as well as that of electron attachment have been taken into consideration.

C. LOW PRESSURE BREAKDOWN IN GASES IN A UNIFORM HIGH FREQUENCY ELECTRIC FIELD

(1) WITHOUT MAGNETIC FIELD (11) WITH A STEADY TRANSVERSE MAGNETIC FIELD.

Dielectric breakdown of air under the action of a high frequency uniform electric field has been studied at a pressure of 1.5μ of mercury in three cylindrical discharge tubes of length 5 cm, 7cm and 15 cm (diameter = 3.5 cm each tube) with external electrodes. Since at this low pressure range, the starting voltage should be independent of the nature of the gas, so starting voltages for air and hydrogen have been obtained in the same discharge tube (length = 15 cm) . The exciting frequency range is limited by the oscillator voltage output. The breakdown voltage against frequency of the applied field curve S shows identical nature for both air and hydrogen. The breakdown voltages at different frequencies are obtained for other two discharge tubes and results obtained are compared with those of the previous workers. It is found that the breakdown voltage is higher in tubes of shorter length and the cut-off wavelength increases with the length of the discharge tube. A new value of the constant appearing in the cut-off law is obtained empirically which is found to satisfy the experimental results for cylindrical discharge tubes of length larger than 2 cm. The breakdown under the present experimental set up is due to secondary electron v_e resonance and following the theory of Gill and Von Engel (1948), Hatch and Williams (1954, 1958) the phase angle ϕ and the K kinetic energy of the oscillating electron at the opposite end have been calculated which are in agreement with results obtained previously.

Starting potentials are also measured in presence of a steady transverse magnetic field varying from 18 gauss to 45 gauss in the discharge tube of length 5 cm. only and in the frequency range permitted by output voltage limitation of the oscillator. It is observed that in presence of steady transverse magnetic field the breakdown voltage as well as the cut-off wavelength increase with the magnetic field. The theory of breakdown in presence of steady magnetic field has been developed following Deb and Goswami (1964) and the effect of the angle of arrival at the end wall on the breakdown mechanism has been considered. The observations with magnetic field and the subsequent fitting of these observations with the theory have yielded the values of the phase angle and the effective kinetic energy of the arrival of the electron with fair amount of accuracy specially for magnetic fields smaller than 30 gauss. The probability of electrons colliding with the side walls has been considered and it has been shown that under the present experimental setup majority of electrons with energy sufficient to cause breakdown are freely transmitted between the two ends of the discharge tube. The validity of the simplifying assumptions made in the theory has been discussed.

D. VARIATION OF LIGHT INTENSITY OF GLOW DISCHARGE IN TRANSVERSE STEADY MAGNETIC FIELD.

The intensity of light from the glow discharge columns of rare gases like neon, argon and helium excited by a uniform radiofrequency electric field has been studied when the columns are placed in a steady magnetic field, transverse to high frequency electric field. The pressure of the gas was fixed at 10 mm of mercury. The total intensity of the visible light, as measured by a photo voltaic surface placed arbitrarily at any position near the columns shows a steady increase with the increase of the magnetic field. The observations

were limited by the maximum value of magnetic field (2000 gauss) as the present setup could not supply higher magnetic field. Spectra have also been photographed for these three gases at different magnetic fields and the intensity profiles of the spectral lines have been obtained. The profiles clearly indicate that the overall increase of total intensity of radiation is always associated with it the increase of intensities of all the spectral lines. The lines show increase of intensity at different rate i.e. the intensity of some of the lines of the column are not seriously effected by the presence of transverse magnetic field. However in the present setup no detailed observation with line spectra is made and so no quantitative approach has been made for explaining the phenomenon. Assuming that the total intensity of radiation is proportional to the total production rate^e of excited levels of atoms, an expression for the intensity of radiation has been obtained. The effect of magnetic field on the intensity has been introduced through the equivalent pressure concept of Belavin and Haydon (1958) and the variation of different parameters in the above expression that are known to be effected in presence of transverse magnetic field are considered. An expression for I_H/I_0 is obtained where I_H is the total intensity of radiation in presence of transverse magnetic field and I_0 is that without magnetic field. The theoretical results agree quite satisfactorily with the experimentally obtained curve of I_H/I_0 against the magnetic field for all the three gases studied. The deviation of the theoretical values from experimental results at very high magnetic field has been attributed to the failure of equivalent pressure concept at high values of (H/P) where P is the pressure of the gas. The uncertainties in the values of the different parameters contributed to a certain extent towards the limitation in the agreement between theoretical and experimental values. A broad field of future work has been pointed out.

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