CHAPTER - VII.

EFFECT OF EXTERNAL MAGNETIC FIELD ON THE INTENSITY OF EMISSION LINES IN THE VISIBLE REGION OF THE SPECTRUM FROM RADIOFREQUENCY DISCHARGE COLUMN.

INTRODUCTION.

Different aspects of the radiation property of the gaseous discharge column excited by d.c. electric field were investigated by many workers for a long time and a fair amount of knowledge has been obtained on different mechanisms of the radiation emitting processes. One of the interesting features of the glow discharge which has not yet been completely understood is the different processes by which the intensity of the radiation from the column changes under different discharge conditions and in presence of external field.

Rossler and Schonherr (1938) identified both pressure and current dependent losses of the radiation of mercury line ($6^3P_1 - 6^1S_0$) and attributed them to collisions of the second kind with neutrals and electrons respectively. Many workers observed decrease in intensity at large density, specially in inert gases. Fowler and Duffendack (1949) found the dependence of the intensity of the spectral lines upon the tube current to be linear within experimental error. This relationship was observed for all types of transitions and over a current range of half m.A. to one hundred mA. All the density vs. intensity curves have essentially the same form, rate of decay and location of the maximum except the transition $2^3P - 3^3D$. The possibility of an unrecognised process other than direct excitation has been suggested from the results of observations of radiation from a low voltage arc in helium as a function of gas density, tube current and tube potential. Duffendack and Koppius (1939) observed increase of intensity of radiation for the family of transitions ending with 6^3P states in the negative glow which shows an exponential saturation with mercury concentration and varies linearly with tube current. Hedges and Michels (1928) observed maxima in the radiation intensity with change of pressure from positive column of helium discharge. Altogether they studied thirteen lines in the visible region. Rokhlin (1939) observed maxima of some resonance lines of mercury vapour discharge by applying longitudinal magnetic field. Kulkarni (1944) studied discharges in some gases, including some rare gases in the apparatus used for observation of Zeeman effect and found the intensity of some of the spectrum lines show maxima at different magnetic field intensities which again was found to depend on wavelength and the presence of foreign gas. Some lines did not however show maxima even at the highest magnetic field intensity available in the setup. No detailed mathematical analysis was put forward.

But very little knowledge both experimental and theoretical, is available on the optical radiation property of high frequency discharge though Beck (1935) in a point to point comparison found steady glow discharge in mercury indistinguishable from 100 Mc/s discharge, and also the identical nature of their radiation property. In view of these observation it will be worthwhile to investigate the radiation property of high frequency discharge and it is proposed in the present investigation to study the effect of transverse d.c. magnetic field on the intensity of optical radiation. The investigation has shown some interesting results of the influence of external magnetic field on the intensity of line radiation. A theory from very elementary considerations has been proposed to explain the results on the change of total optical radiation intensity of the column.

EXPERIMENTAL ARRANGEMENT.

The discharge tubes are fitted with aluminium electrodes and filled with gases neon, argon and helium respectively which are spectroscopically pure and at a pressure of 10 m.m. mercury as supplied by the manufacturer. These tubes are the same as were used in an earlier experiment while studying breakdown in combined radiofrequency and d.c. field. The high frequency field is supplied by a tuned plate tuned grid oscillator. The uniform magnetic field is applied by an electromagnet which is calibrated by a gaussmeter. The photovoltaic surface connected with a galvanometer measures the relative intensity of the total radiation from the column.

A constant deviation spectrometer with glass prism is used to obtain the spectrum of the discharge column in the visible region. A camera with sliding arrangement photographs the spectrum. The photographs of the spectra are later analysed by a microphotometer arrangement and the intensity profiles are obtained for each line. Care has been taken to see that exposure time for different sets of spectra of the same gas at different magnetic fields remain rigidly the same.

RESULTS AND DISCUSSION.

High frequency discharge falls in the catagory of thermal electron discharges. Analysis of the radiation from the thermal discharges must be made on the basis of electron concentration and its velocity distribution. It is reasonably accurate to consider that the electron temperature which governs the velocity distribution remains constant over large regions of the discharge. This is because the electron temperature is almost directly proportional to the electrostatic field in the gas and the electrostatic field is tangentially constant, at least, from its conservative properties. In the absence of space charge, there can be no change in normal component either, thus establishing the conditions for constancy of electron temperature.

In the steady state of the glow discharge column at a fixed pressure, the electrons colliding with neutral atom may excite it or ionise it. Since excitation potential is much lower than ionisation potential, so an electron on the average suffers a large number of inelastic exciting collisions with neutral atoms before it actually ionises an atom. In the steady state, the average population in an excitation level determines the intensity of the line. The process of populating a level by electron collision with neutral atom is dependent upon the rate of collison, excitation cross section and density of the colliding particles. Consequently, it is most likely that any external influence changing the rate of collision and density of colliding particles will effect the population density of different excitation levels and thereby cause a change in intensity.

The change of population in a given state of excitation due to collisional interaction between electron and atom is represented by the production function P which can be written for elatations of a type having the cross-section $\sigma_{jo}(u)$ per unit volume per unit time as : (Fowler 1956)

$$P_j = 4\pi (N_-) \int_{u_{min}}^{\infty} u^3 . \sigma_{jo} . \phi . du \qquad ...(7.1)$$

where u = relative velocity of interacting electron and atom which is practically the velocity of electrons as atom's velocity is very small compared to electron.

N_- = electron density

P_j = production function for j^{th} state of excitation from ground state, the corresponding radiation frequency being ν_{jo}.

u_{min} = minimum velocity of electron for which $\sigma_{jo} = 0$

ϕ = Maxwell - Boltman distribution function.

Following Fowler (1956), for gases which do not attach electrons, the production function is directly proportional to the current density and if radiation is the chief energy loss mechanism, the radiation must be proportional to the current just as in monoenergetic electron discharge. Consequently we can take production function to be proportional to total intensity of radiation. The production function for all types of excitation can be obtained by taking summation over j, provided we assume that all the transitions are between ground state and excited level. The total production function

$$P = \sum_j P_j = \sum_j 4\pi (N_-) \int_{u_{min}}^{\infty} u^3 \cdot \sigma_{j0} \cdot \Phi \cdot du$$

Consequently, we can take the total intensity I of the complete radiation coming out of a discharge column as proportional to P. Therefore

$$I \propto \sum_j 4\pi (N_-) \int_{u_{min}}^{\infty} u^3 \cdot \sigma_{j0} \cdot \Phi \cdot du \qquad \ldots(7.2)$$

Mott and Massey (1950) found that for optically allowed transitions, the cross -section is approximately given by

$$\sigma_{j0} \approx \frac{3}{4\pi} \cdot \frac{e^2 c^3}{h} \cdot \frac{A_{j0}}{u^2 \nu_{j0}^3} \cdot \log\left(2 m u^2 / h \nu_{j0}\right)$$

where A_{j0} = Einstein's transition probability

C = velocity of light

h = planck's constant

We have assumed here that electrons are distributed following Maxwell - Boltzman distribution law and constitutes the electron gas at a temperature T_e which is called the electron temperature, a measure of energy of the electrons. Consequently, the pressure of the electron gas is given by

$$P_e = (N_-) K T_e$$

where K is Boltzman constant

Putting the value of Φ and σ_{j0} into equation (7.1) we get

$$P_j = 4\pi(N_-).\int_{u_{min}}^{\infty} u^3 . (m/2\pi K T_e)^{3/2} . \exp(-mu^2/2KT_e) . \frac{3e^2c^3A_{j0}}{4\pi h\, \nu_{j0}^3\, u^2} . \log(2mu^2/h\nu_{j0}) . du .$$

$$\therefore P_j = 4\pi(N_-).(m/2\pi K T_e)^{3/2} . \frac{3e^2c^3A_{j0}}{4\pi h\, \nu_{j0}^3} . \int_{u_{min}}^{\infty} u . \exp(-mu^2/2KT_e) . \log(2mu^2/h\nu_{j0}) . du$$

Without going to evaluate exactly the right hand side of the above equation, if we consider only the terms involving T_e and P_e, then as a first approximation it can be said that

$$P_j \propto \frac{P_e}{T_e^{5/2}} \exp\left[-m\, u_{min}^2/2KT_e\right]$$

And since $P = \sum_j P_j$ so we get

$$P \propto \frac{P_e}{T_e^{5/2}} \exp\left[-m\, u_{min}^2/2KT_e\right] \qquad \text{...(7.3)}$$

which is proportional to the intensity of total radiation from the column

When a transverse magnetic field is applied to the discharge column, the column is constricted. Due to this constriction of the column, the electron collision and hence the equivalent pressure of the electron column increases. The decrease of the mean free path results in the decrease in the average energy gained by an electron between two successive collisions with neutral atom. Consequently the electron temperature decreases (Von Engel 1955, Sen and Gupta 1967). So from the very simple consideration, the overall effect of the application of steady transverse magnetic field on the radiation property of the discharge column can be accounted for by the change of P_e and T_e with magnetic field only and assuming that other factors arising in equation (7.3) remain uneffected by the magnetic field.

Let us assume that in presence of magnetic field, the values of P_e and T_e are given by P_{eH} and T_{eH} . Blevin and Hayden (1958) provided a relation between P_{eH} and P_{eo} as

$$P_{eH} = P_{eo}\left[1 + C\left(H/P_{eo}\right)^2\right]^{1/2}$$

...(7.4)

The term $C = (e/m)(L/v_r)$ where L is the mean free path of electron at a pressure of 1 m.m. mercury and v_r is the random velocity of electron, and H is the magnetic field. The authors assumed C to be constant within the value of H/P_{eo} = 300 GAUSS/m.m. of Hg.

The relation between T_e and P, as given by Von Engel (1955) is

$$x^{-1/2} \exp(x) = \beta\left(\ell P R\right)^2$$

...(7.5)

where $x = eV_i/KT_e$ and $\ell = \left(aV_i^{1/2}/\bar{K}+P\right)$, P = Pressure and β is a numerical constant.

Here $\bar{K}^{+}$ = mobility coefficient of positive ion.

V_i = ionisation potential

a = initial slope of the efficiency of ionisation curve.

Following Sen and Gupta (1967) it is assumed that T_{eo}, P_{eo} and T_{eH}, P_{eH} are the temperature and pressure of the electron gas without and with external magnetic field respectively which satisfy the relation (7.5).

Hence

$$\frac{\exp\left(eV_i/KT_{eH}\right)}{\exp\left(eV_i/KT_{eo}\right)}\left(\frac{T_{eH}}{T_{eo}}\right)^{1/2} = \left(\frac{P_{eH}}{P_{eo}}\right)$$

Assuming $T_{eo} - T_{eH} = \Delta T_e$; where $\Delta T_e \ll T_{eo}$ (Sen and Gupta 1967) and simplifying we get

$$T_{eo} - T_{eH} = \frac{2T_{eo}^{2}\log\left(P_{eH}/P_{eo}\right)}{T_{eo} + 2eV_i/K}$$

$$\therefore T_{eH} = T_{eo} - \left\{2T_{eo}^{2}\log\left(P_{eH}/P_{eo}\right)\Big/ T_{eo} + 2eV_i/K\right\} \qquad \ldots(7.6)$$

If total production function in presence of magnetic field be P_H and corresponding intensity of total radiation I_H, then using relations (7.2), (7.3), (7.4), we get

$$\frac{P_H}{P_o} = \frac{I_H}{I_o} = \left(\frac{P_{eH}}{P_{eo}}\right)\left(\frac{T_{eo}}{T_{eH}}\right)^{5/2}\exp\left[-\frac{\mathcal{E}_m}{K}\left(\frac{1}{T_{eH}} - \frac{1}{T_{eo}}\right)\right]$$

where $\mathcal{E}_m = \frac{1}{2}mU_{min}^{2}$ = minimum excitation energy

$$I_H/I_o = \left(\frac{P_{eH}}{P_{eo}}\right)\left(\frac{T_{eo}}{T_{eH}}\right)^{5/2}\exp\left[-\frac{\mathcal{E}_m}{K}\cdot\frac{T_{eo}-T_{eH}}{T_{eo}^{2}}\right] \quad \ldots$$

if we assume $T_{eH}T_{eo} \approx T_{eo}^{2}$

Putting the value of T_{eH} from equation (7.6)

$$I_H/I_0 = \left(\frac{P_{eH}}{P_{e0}}\right)\left[\frac{1}{1-2T_{e0}\log\left(P_{eH}/P_{e0}\right)/T_{e0}+2eV_i/K}\right]^{5/2}\exp\left[-\frac{\mathcal{E}_m}{K}\cdot\frac{2\log\left(P_{eH}/P_{e0}\right)}{T_{e0}+2eV_i/K}\right]$$

Taking log of both sides we get

$$\log\left(\frac{I_H}{I_0}\right) = \log\left(\frac{P_{eH}}{P_{e0}}\right) + \frac{5}{2}\log\left[\frac{1}{1-\dfrac{2T_{e0}\log\left(P_{eH}/P_{e0}\right)}{T_{e0}+2eV_i/K}}\right] - \frac{\mathcal{E}_m}{K}\cdot\frac{2\log\left(P_{eH}/P_{e0}\right)}{T_{e0}+2eV_i/K}$$

since $\left\{2T_{e0}\log\left(P_{eH}/P_{e0}\right)/T_{e0}+2eV_i/K\right\} \ll 1$ the above equation reduces to

$$\log\left(\frac{I_H}{I_0}\right) = \log\left(\frac{P_{eH}}{P_{e0}}\right) + \frac{5}{2}\cdot\frac{2T_{e0}\log\left(P_{eH}/P_{e0}\right)}{T_{e0}+2eV_i/K} - \frac{2\mathcal{E}_m\log\left(P_{eH}/P_{e0}\right)}{T_{e0}+2eV_i/K}$$

$$= \left[1+\frac{5T_{e0}}{T_{e0}+2eV_i/K} - \frac{2\mathcal{E}_m}{K\left(T_{e0}+2eV_i/K\right)}\right]\log\left(\frac{P_{eH}}{P_{e0}}\right)$$

$$= \alpha\log\left(\frac{P_{eH}}{P_{e0}}\right)$$

where $\alpha = 1 + \dfrac{5T_{e0}}{T_{e0}+2eV_i/K} - \dfrac{2\mathcal{E}_m}{K\left(T_{e0}+2eV_i/K\right)}$ ...(7.7a)

Hence $I_H/I_0 = \left(\dfrac{P_{eH}}{P_{e0}}\right)^{\alpha} = \left\{1 + C\left(H/P_{e0}\right)^2\right\}^{\alpha/2}$ ...(7.7b)

The values of the different quantities of expression (7.7) is tabulated and shown in table I for the three gases.

TABLE - I.

Gas	$\left(\frac{2eV_i}{K}\right)$ $\times 10^{-5}$ °K	V_i volts	$\mathcal{E}_m$ e.v.	$C\times10^3$	$\left(\frac{T_{e_0}}{V_i}\right)$ $\times 10^{-2}$ °K/Volts.	Radius of the tube "R" cm.	$\ell\times10^3$	α	Pressure P_{e_0} m.m. Hg.
Neon	5.035	21.5	16	1.93	9	.9	6	.4852	10
Helium	5.74	24.5	18	.23	10	.8	4	.5172	10
Argon	3.713	15.7	10.8	2	7.5	.8	40	.5092	10

The values of the constants of second and third columns are taken from Von Engel (1956), that of fourth column from the works of Druyvesteyn and Penning (1940) and of sixth and eigth columns from Von Engel (1955) from which the values of T_{e_0} are taken utilising the universal curve of T_{e_0}/V_i against ℓPR where ℓ is a constant , R the radius ofthe tube. The values of "c" are chosen by fitting the equation (7.7b) with the experimental curve, as there are no reliable values of "c" for rare gases. The ratio of the intensity of the total radiation from a column with and without magnetic field is obtained directly by taking the ratio of the galvanometer deflections at two values of the magnetic field keeping the maintainance voltage constant. These ratio I_H/I_0 is plotted against magnetic field H in figs. 30, 31, 32 . In all the three gases studied (Ni, Ne, A) it is observed that the ratio of the intensity of the total radiation increases with the increase of the magnetic field, but at very high magnetic field the curves show a saturation effect as is observed by the fall of the rate of rise of the quantity I_H/I_0 . However, the present setup could not provide us with magnetic field of very high intensity to investigate whether the curves show a maximum and then decrease. Presently, work is being carried out with a new setup

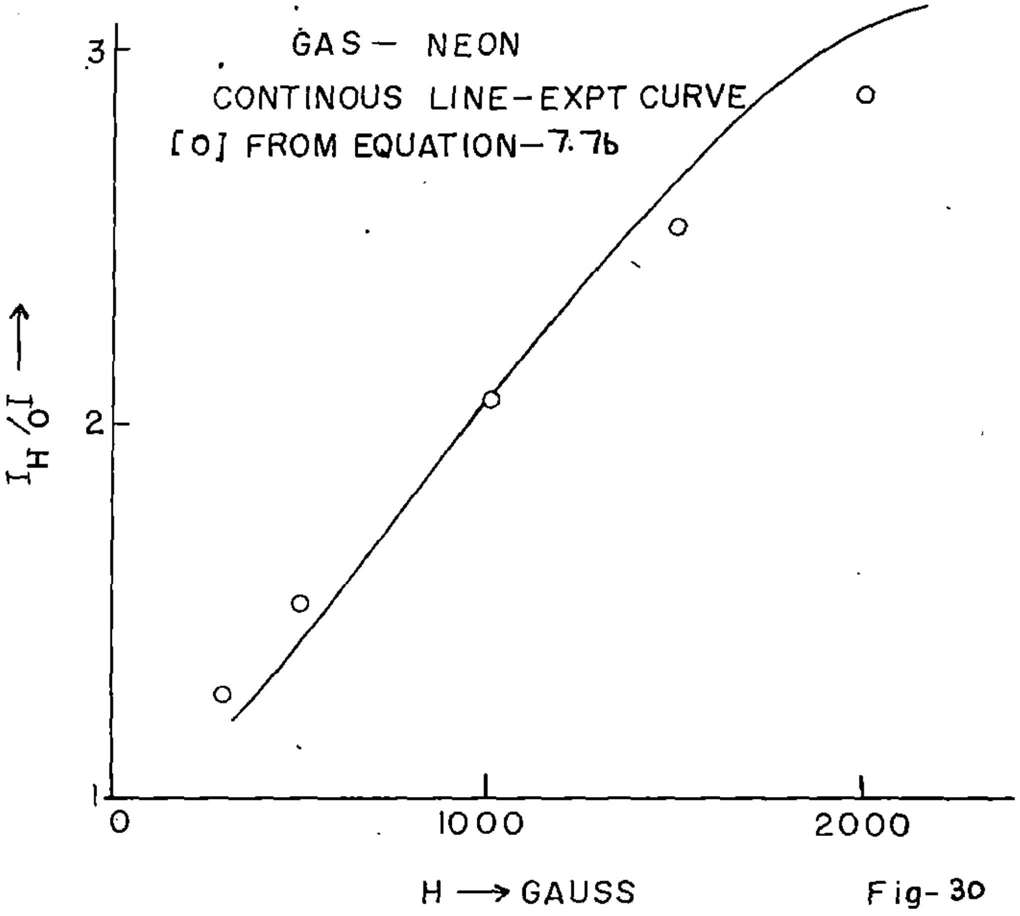
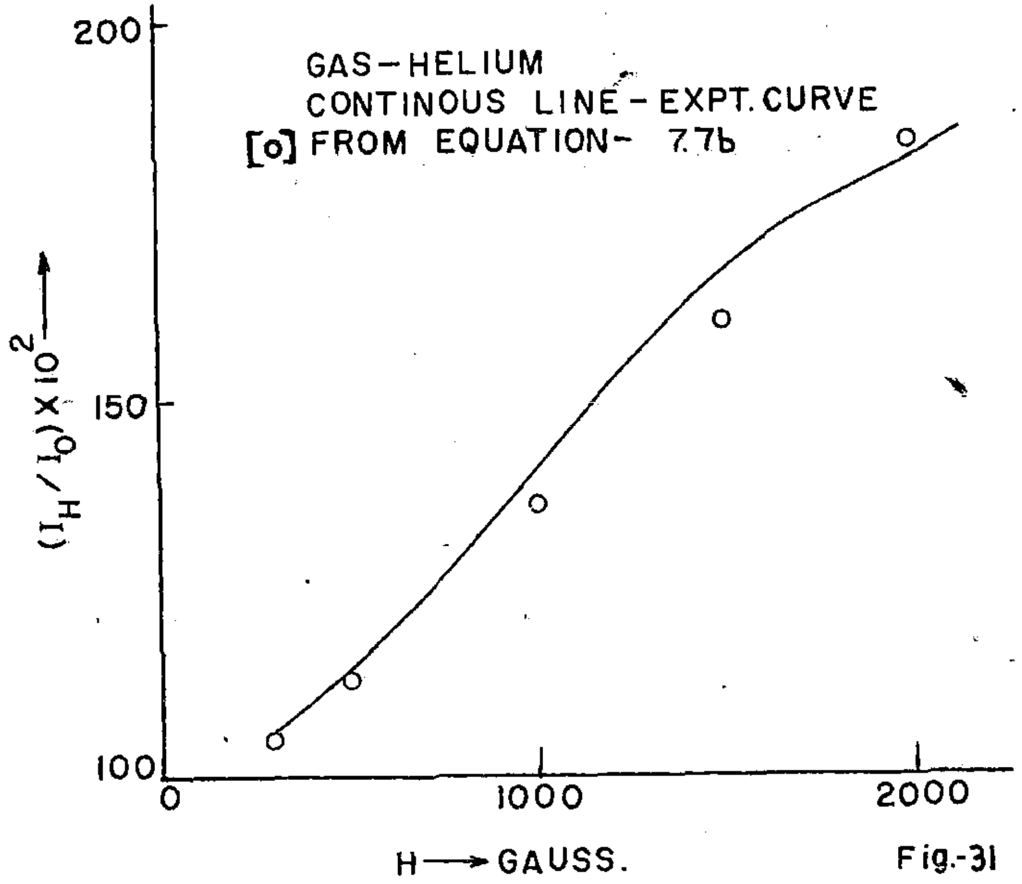

GAS — NEON
CONTINOUS LINE—EXPT CURVE
[O] FROM EQUATION—7.7b
3
2
1
I_H/I_0 →
0
1000
2000
H → GAUSS

Fig-30



200
150
100
$(I_H / I_0) \times 10^2$ →
GAS-HELIUM
CONTINOUS LINE-EXPT. CURVE
[o] FROM EQUATION- 7.7b
0
1000
2000
H → GAUSS.

Fig.-31

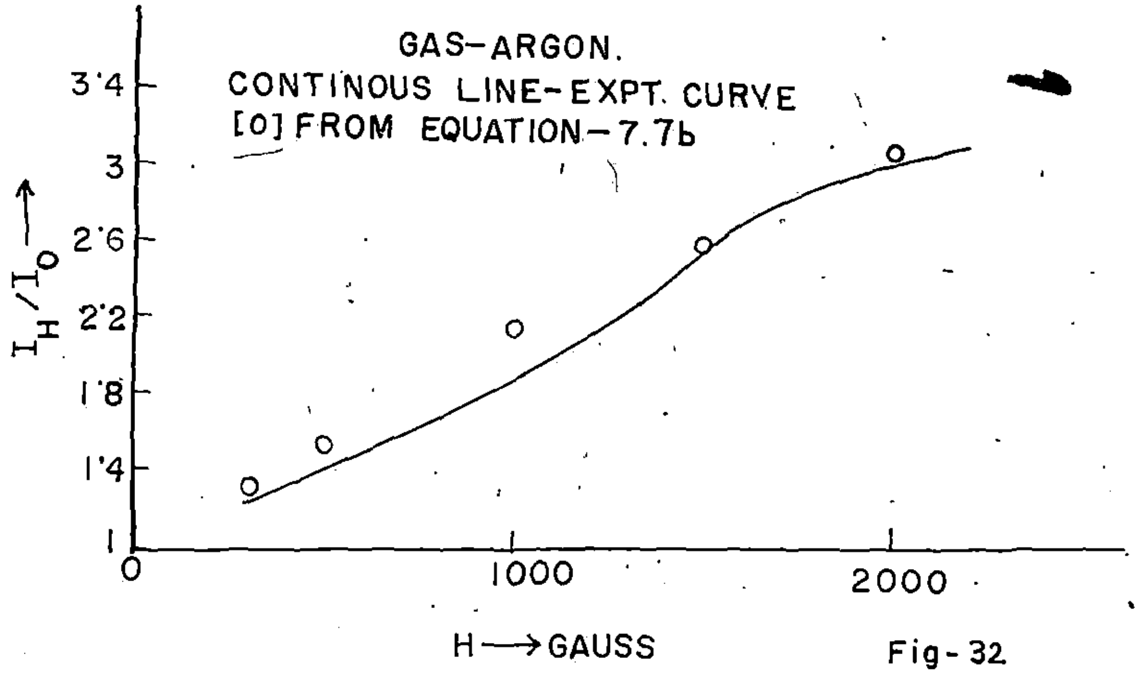

GAS-ARGON.
CONTINOUS LINE-EXPT. CURVE
[O] FROM EQUATION-7.7b
3'4
3
2'6
2'2
1'8
1'4
1
0
1000
2000
I_H/I_0 →
H → GAUSS

Fig-32

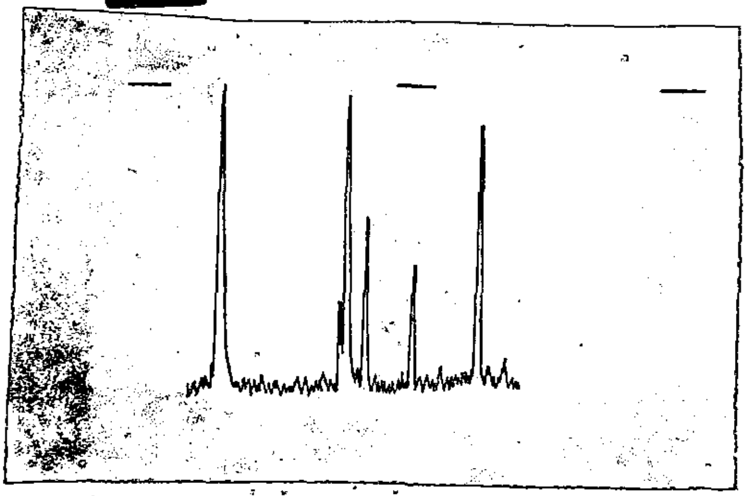
to investigate the case in a strong magnetic field.

The enhancement of the total radiation by the application of the magnetic field is always associated with the increase of the intensity of individual lines of the spectrum. The photographs of the spectra of some arbitrary regions of three gas discharge columns are shown in figs. 33, 34, 35 along with the information of the enviorement at which the photographs were taken and the respective microphotometer tracing of the intensity profiles are also given. The intensity profile curves show that the different spectral lines increase at different rate when magnetic field is applied. The present microphotometer tracer beam could not penetrate through the darkest lines photographed i.e. lines of high intensity. The tracing of all the moderately intense lines that are photographed show a marked increase in the magnetic field but at different rate. However the increase of intensity of bright lines can be seen in the photographs itself. Consequently we can say that the increase of intensity of total radiation is always associated with the increase of intensity of the different lines of the spectra of the discharge column. It may be such that the total enhanced radiaton is equally distributed among the different excitation levels, and as the initial populations of the excitaion levels are different, the lines are increased in different ratio. Further analysis of the line~~s~~ radiation require~~s~~ information about population and excitation mode of the individual line~~s~~ without which it is not possible to arrive at some quantitative results.

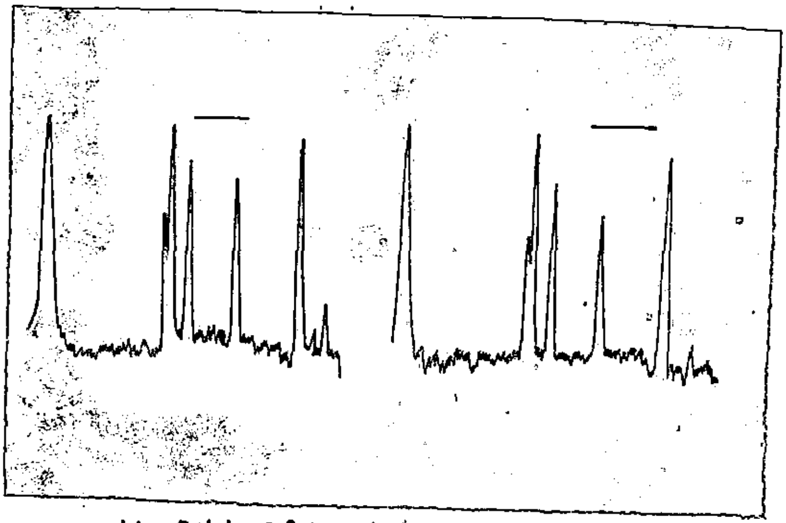
Comparison of the theoretical points obtained from equation (7.~~6~~7b) and the solid experimental curves in figs. 30, 31, 32 show a fair amount of agreement between theory and experiment throughout the range of observation for all gases when computed values of 'C' are used. Nonavailability of any reliable values of C led to the computation of the values of C which is open to criticism as a source of error. The value of C so obtained shows not much divergence from

GAS – HELIUM.

SOURCE – R.F. DISCHARGE TUBE.
FREQUENCY OF EXCITATION = 4·1 Mc/s
MAINTAINANCE VOLTAGE = 160 Volts.(r.m.s.)



H = 0 GAUSS



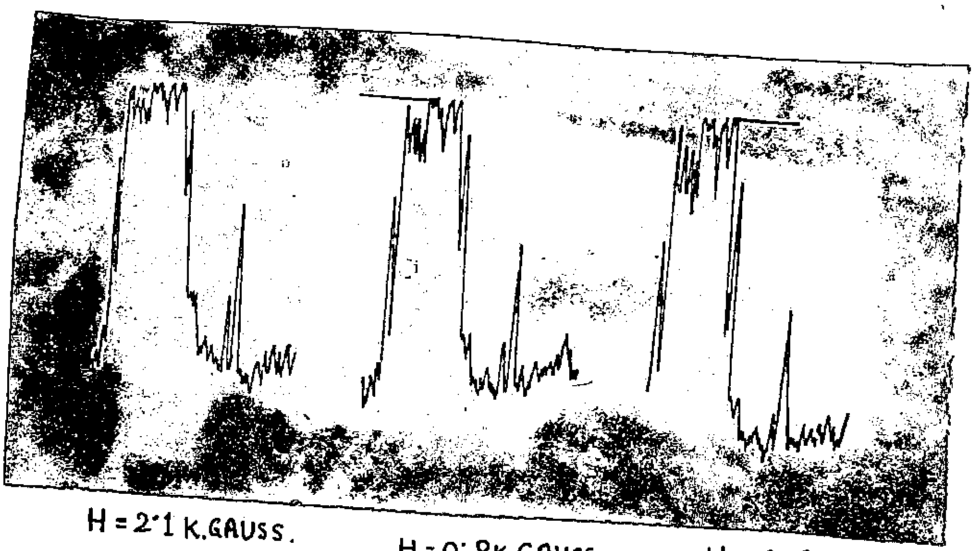
H = 2·1 K. GAUSS H = 0·8 K GAUSS

⟹ DIRECTION OF MICROPHOTOMETER TRACER BEAM

Fig. 33.

GAS – NEON

SOURCE – R.F. DISCHARGE TUBE.
FREQUENCY OF EXCITATION = 4·1 Mc/s.
MAINTAINANCE VOLTAGE = 180 Volts(r.m.s.)

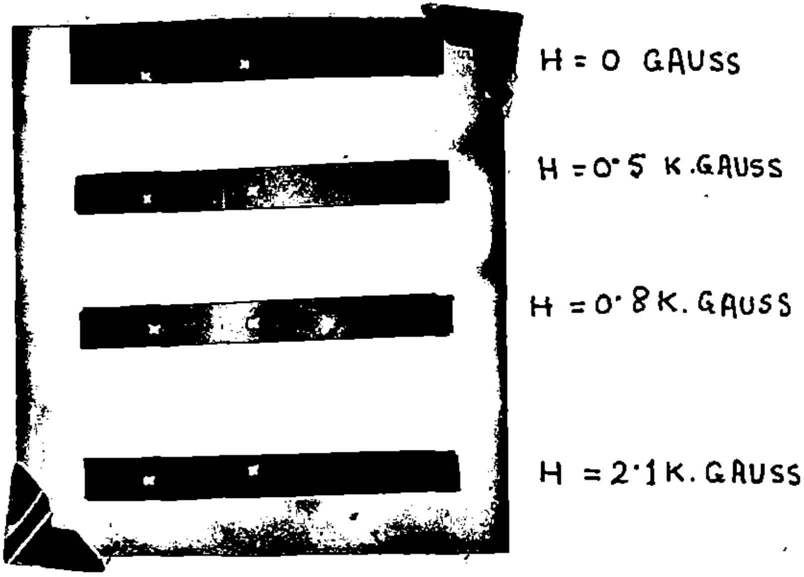


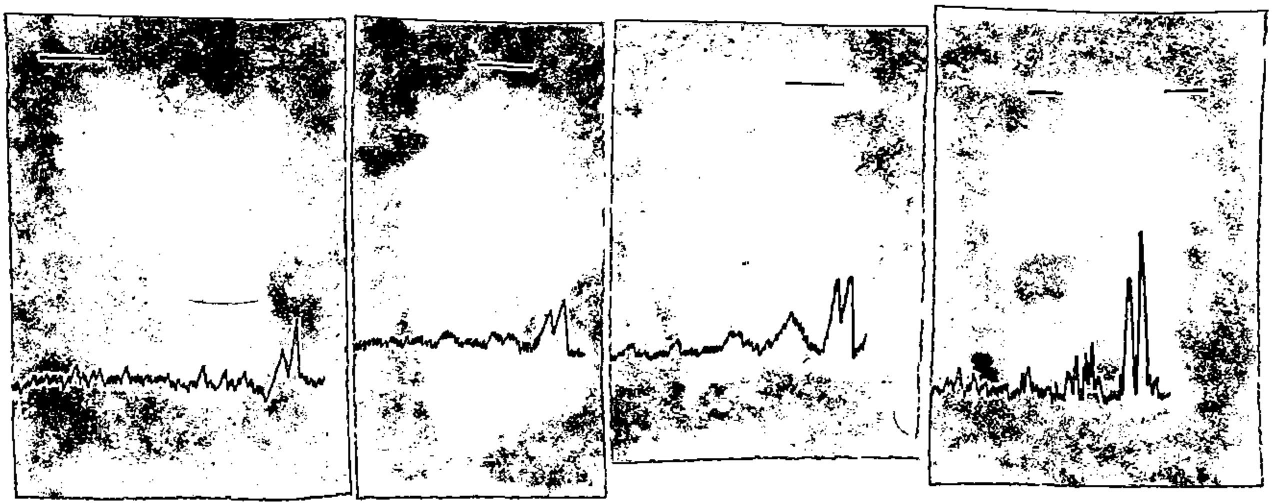
⟹ DIRECTION OF MICROPHOTOMETER TRACER BEAM

Fig 34.

GAS - ARGON

SOURCE - R.F. DISCHARGE TUBE.
FREQUENCY OF EXCITATION = 4·1 Mc/s.
MAINTAINANCE VOLTAGE = 140 Volts(r.m.s.)




H = 0 GAUSS H = 0·5 K.GAUSS H = 0·8 K.GAUSS H = 2·1 K.GAUSS

⟹ DIRECTION OF MICROPHOTOMETER TRACER BEAM

Fig. 35.

the values used by the previous authors and also approximate values calculated from the definition of C . Moreover the assumption that C is independent of magnetic field is not valid as has been shown by Blevin and Haydon (1961), Sen and Gupta (1967) because C is a function of ν_r , the random velocity which is itself a function of the magnetic field. The uncertainity in the measurements of ν_r and also L , the mean free path at 1 m.m. Hg. fails to give any reliable value of C even at low magnetic field which is the main reason for the necessity of computation of its value. However, the present computed values of C lie very close to values given by Sen and Gupta (1967) for He, Ne and A, and the discrepancy between the respective values of C may be attributed to the experimental conditions which is different from that of the present work.

It may be mentioned here that in assessing the effect of magnetic field on the radiating column, only consideration is made about the influence of the magnetic field on two parameters P_{e_0} and T_{e_0} which is a known fact but possibility of having some effect on other parameters involved in the mechanism can not be ruled out.

The saturation tendency of I_H/I_0 at high magnetic field could not be explained by the present simple theory though it can explain the result upto H/P_{e_0} = 200 gauss/ m.m. Hg. The reason for the short-fall of the theory may be attributed to the doubtful validity of the expression for T_{e_H} at high magnetic field and acceptance of C as independent of H.

Considering the uncertainities in the computed values of C and validity of the different expressions for the variation of the parameters P_{e_0} and T_{e_0} in the range of work, the theoretical approach may be said to have a fair amount of success in explaining the present experimental results for neon, argon and helium.

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