CHAPTER - VII.

SPECTRAL LINE INTENSITIES IN GLOW DISCHARGE IN A TRANSVERSE MAGNETIC FIELD.

INTRODUCTION.

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 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 ($6^3 P_1 - 6^1 S_0$) and attributed them to collisions of the second kind with neutrals and electrons respectively. Many observers found decrease of intensity at large density specially in inert gases. Fowler and Duffendack (1949) found the dependence of the intensity of spectral lines upon the tube current to be linear within experimental error. Duffendack and Koppins (1939) observed increase of intensity of radiation for the family of transitions ending with 6^3P states in a negative glow. Hodges and Michels (1928) observed maxima in the radiation intensity with change of pressure in the positive column of helium discharge.

Besides the above parameters the effect of an external magnetic field on the intensity of the spectral lines has been studied by Rokhlin (1939) and by Fabrikant and Rokhlin (1938, 1939). The spectroscopic method has the advantage of studying the behaviour of fast electrons of energy greater than the excitation energy of the gas. Rokhlin studied the intensity distribution of the spectral lines of mercury ($P = 10^{-3}$ mm. of Hg; $i = 1.5$ to 4 amp;), with coincident magnetic field the discharge is visibly constricted into a chord and the electron energy distribution is found to be constant across the chord of the tube. With increasing magnetic field the intensity in case of Hg. line $\lambda = 5791.A^\circ$ and $\lambda = 3906\ A^\circ$ gradually increases and attaining a maximum value gradually falls. Experiments have also been made on the effect of magnetic field on the radiation from the column of a constricted discharge by Kulkarni (1944) who studied the discharge in He, Ne and N_2 in a transverse magnetic field.

It was observed that the intensity reaches a maximum and then quickly decreases with increasing magnetic field. The value of the magnetic field at the intensity maximum depends on the wavelength of the line and on the presence of any foreign gas. No theoretical explanation of the phenomena was however provided.

But very little information, both experimental and theoretical is available on the optical radiations property of high frequency discharge though Eeck (1935) in a point to point comparison found the identical nature of radiation property of both types of discharges. In the present investigation it is proposed to study the effect of a transverse magnetic field on the intensity variation of spectral lines excited by a radiofrequency source in a variable transverse magnetic field as it will provide some information regarding the variation of energy of electrons greater than the excitation energy of the atom. The study will also indicate whether the source of excitation has any effect on the intensity distribution of spectral lines and its variation in a transverse magnetic field; The present investigation reports the preliminary results in case of helium, hydrogen and mercury vapour.

EXPERIMENTAL ARRANGEMENT.

The discharge tubes are fitted with aluminium electrodes and filled with spectroscopically pure gases such as hydrogen, helium and mercury vapour at a pressure of 3 mm. of mercury. An accurately calibrated constant deviation spectrograph has been used to measure the wave length of the spectral lines. A photo electric cell supplied by Messers Eel Photo Company, serves as a photo surface which yeilds photoelectrons on exposure to light. The output from the photo surface is connected directly to the Microvolt meter (Philips Model G.M. 6020) and the intensity of the spectral line is directly proportional to the current following through the microvoltmeter. After removing the eye piece a particular spectral line was brought to focus on the photo voltaic surface and a magnetic field previously calibrated (0 - 4000 gauss) was placed transversely across the length of the discharge tube. The intensity was measured both in the absence and in presence of the magnetic field. The high frequency source used for excitation of the discharge is a tuned plate tuned grid oscillator and the frequency ofexcitation is 10 Mc/sec. The block diagram of the experimental arrangement is shown in fig. (7.1).

RESULTS AND DISCUSSION.

Some of the emission lines of hydrogen, helium and mercury vapour have been investigated in the present case and the experimental results have been plotted in fig. (7.2 to 7.4). It is observed that in each case the ratio I_H/I where I_H is the intensity in presence of magnetic field and I, the intensity in its absence, graduall rises and attaining a maximum value at a particular value of the magnetic field which is different for different wave lengths gradually falls with the further increase of the magnetic field. The experimental results have been entered in Table (7.1).

TABLE - (7.1).

Gas	Wavelength in A°	$\left(\frac{I_H}{I}\right)_{max}$	H_{max} in gauss.
Hydrogen	6562.73	1.26	750
	4861.33	1.4	680
	4340.47	1.82	2460
	4101.74	3.54	2440
Helium	5875.87	1.62	2140
	4471.48	2.54	2450
	6678.15	2.84	2700
	5015.67	3.19	3100
Mercury vapour	5790.65	2.04	1250
	4358.35	2.1	1450
	5460.74	2.6	1640

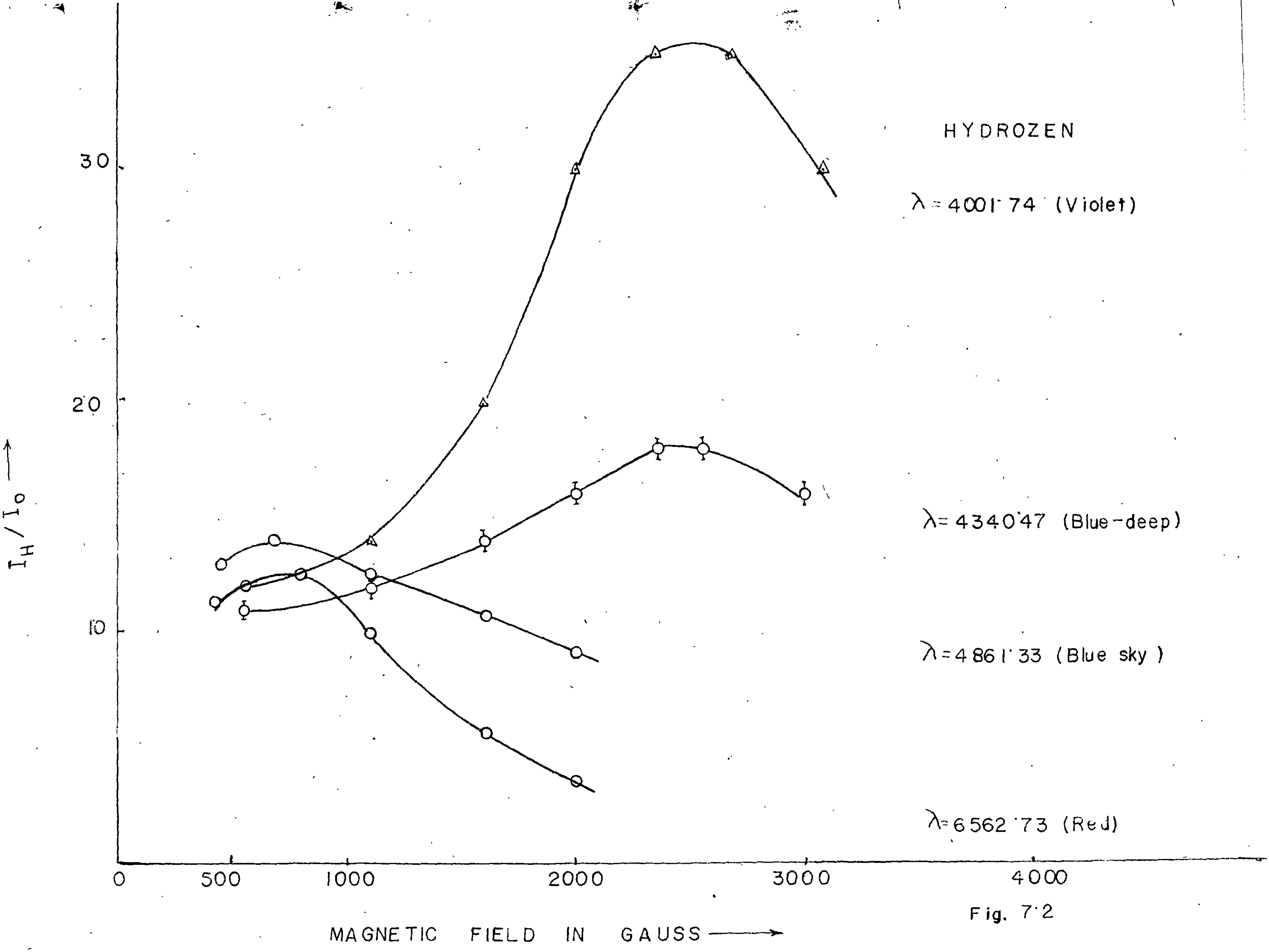
HYDROZEN
λ = 4001·74 (Violet)
λ = 4340·47 (Blue-deep)
λ = 4861·33 (Blue sky)
λ = 6562·73 (Red)
I_H / I_o →
30
20
10
0
500
1000
2000
3000
4000
MAGNETIC FIELD IN GAUSS →

Fig. 7·2

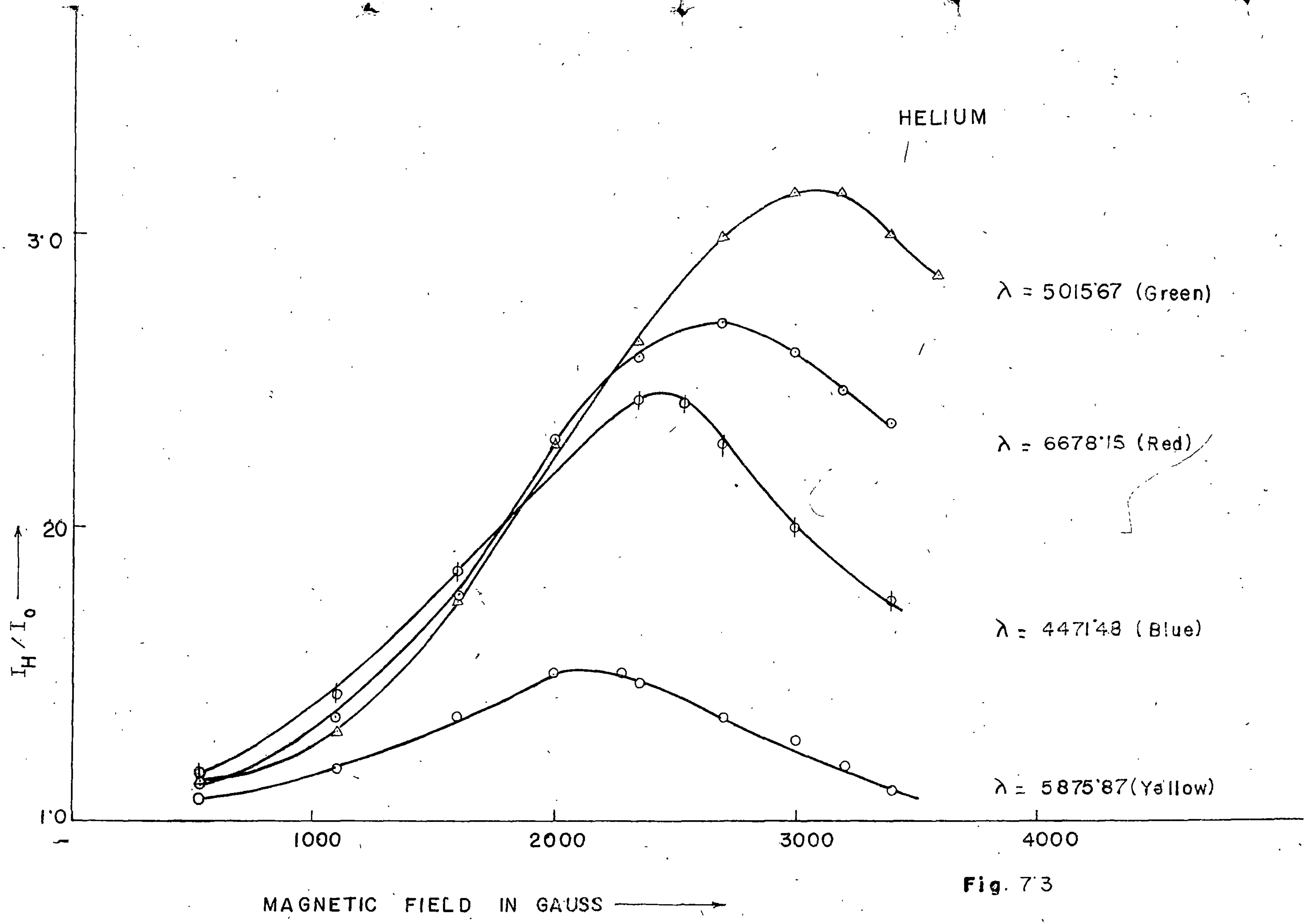
HELIUM
3·0
20
1·0
I_H / I_o →
1000
2000
3000
4000
MAGNETIC FIELD IN GAUSS →
λ = 5015·67 (Green)
λ = 6678·15 (Red)
λ = 4471·48 (Blue)
λ = 5875·87 (Yellow)

Fig. 7·3

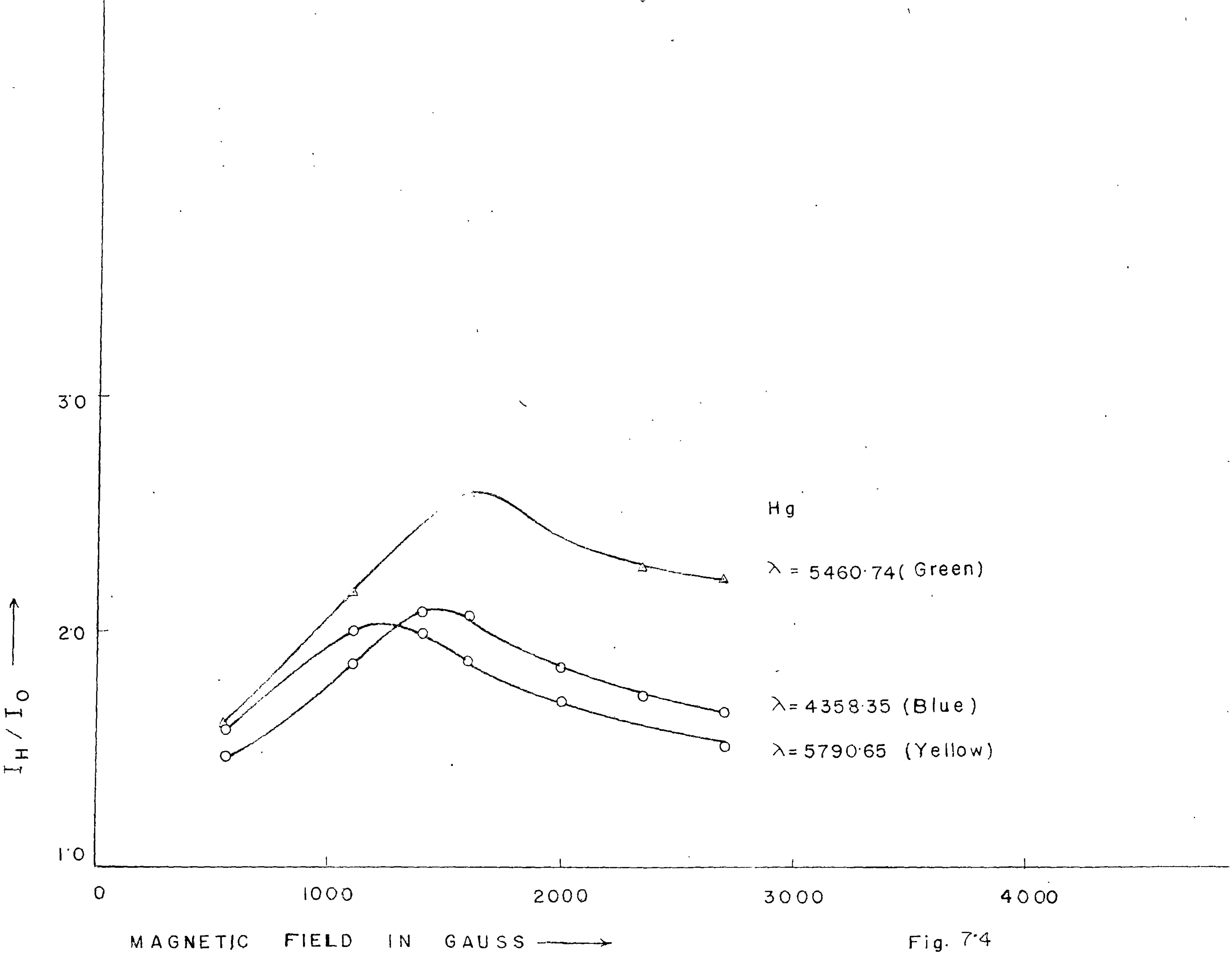
Hg
λ = 5460·74 (Green)
λ = 4358·35 (Blue)
λ = 5790·65 (Yellow)
3·0
2·0
1·0
0
1000
2000
3000
4000
I_H / I_O →
MAGNETIC FIELD IN GAUSS →

Fig. 7·4

To explain the observed results it has been assumed after Rokhlin (1939) that two opposing factors which affect the intensity of the spectral line come into play when a magnetic field is present. The maximum has been supposed to be due to two opposing effects, the increase of electron concentration at the centre due to magnetic field and the decrease in their energy. This is equivalent to saying that due to presence of magnetic field, the equivalent pressure increases according to the relation.

$$P_H = P\left[1 + C_1 H^2/P^2\right]^{1/2} \qquad \ldots(7.1).$$

where $C_1 = (eL/mv_r)^2$ as introduced previously and the energy of the electron that is the electron temperature decreases according to the equation as deduced by Sen and Gupta (1969)

$$T_{eH} = T_e - \frac{2\,T_e^2 \log(P_H/P)}{T_e + 2eV_i/K} \qquad \ldots(7.2).$$

where V_i is the ionization potential of the atom and other symbols have their usual significance. The intensity of a spectral line due to transition between the upper level U and lower level l, is given by

$$I(T) = n_- \frac{g_u}{Z_o} A_{ul}\, h\nu_{ul}\, e^{-U/KT_e} \qquad \ldots(7.3).$$

where n_- is the electron density per unit volume Z_o is the internal partition function, g_u is the statistical weight of the upper level, U is the energy associated with the upper state A_{ul} is Einstein's coefficient of probability namely the number of probable transitions per unit time and $h\nu_{ul}$ is the frequency of emitted quanta.

Now $n_{-} = P / K T_e$ and when the transverse magnetic field is applied

$$n_H = P_H / K T_{eH}$$

and the intensity of the spectral line in presence of magnetic field can be written as

$$I_H = n_H \frac{g_u}{Z_0} A_{ul} \, h \nu_{ul} \, e^{-U/K T_{eH}}$$

...(7.4).

Hence from equation (7.3) and (7.4).

$$\frac{I_H}{I} = \frac{n_H}{n_{-}} e^{-\frac{U}{K}\left[\frac{1}{T_{eH}} - \frac{1}{T_e}\right]}$$

$$= \frac{P_H}{P} \cdot \frac{T_e}{T_{eH}} \cdot e^{-\frac{U}{K}\left[\frac{T_e - T_{eH}}{T_e T_{eH}}\right]}$$

$$= \left[1 + C_1 H^2/p^2\right]^{1/2} \frac{T_e}{T_{eH}} \cdot\cdot e^{-\frac{U}{K}\left[\frac{T_e - T_{eH}}{T_e T_{eH}}\right]}$$

$$= \left[1 + C_1 H^2/p^2\right]^{1/2} \frac{T_e}{T_{eH}} e^{-\frac{U}{K}\left(\frac{T_e - T_{eH}}{T_e T_e}\right)} \quad \text{assuming } T_e \approx T$$

...(7.5).

Then maximising $$\frac{d}{dH}\left(\frac{I_H}{I}\right) = \frac{1}{2}\left(1 + C_1 H^2/p^2\right)^{1/2} \frac{C_1}{p^2} 2H \frac{T_e}{T_{eH}} e^{-\frac{U}{K}\cdot\left(\frac{T_e - T_{eH}}{T_e T_{eH}}\right)}$$

$$- \left(1 + C_1 H^2/p^2\right)^{1/2} \frac{T_e}{T_{eH}^2} \frac{dT_{eH}}{dH} e^{-\frac{U}{K}\cdot\left(\frac{T_e - T_{eH}}{T_e T_{eH}}\right)}$$

$$+ \left(1 + C_1 H^2/p^2\right)^{1/2} \frac{T_e}{T_{eH}} e^{-\frac{U}{K}\left(\frac{T_e - T_{eH}}{T_e T_{eH}}\right)} \frac{U}{K T_e T_{eH}} \frac{dT_{eH}}{dH} = 0$$

and as a first approximation assuming $T_e \approx T_{eH}$

$$\frac{C_1 H}{p^2 + C_1 H^2} = -\frac{1}{T_e}\cdot\frac{dT_{eH}}{dH}\left(\frac{U}{KT_e} - 1\right) = -a \text{ (say)}$$

Where $a = \frac{1}{T_e}\left(\frac{U}{KT_e} - 1\right)\frac{dT_{eH}}{dH}$

Hence $aC_1H^2 + C_1H + ap^2 = 0$

or $$H_{max} = \frac{-C_1 \pm \sqrt{C_1^2 - 4a^2C_1p^2}}{2aC_1} \qquad \text{...(7.6).}$$

Since

$$T_{eH} = T_e - \frac{2T_e^2 \log(P_H/p)}{T_e + 2eV_i/K}$$

$$= T_e - \frac{2T_e^2 \log\left(1 + C_1H^2/p^2\right)^{1/2}}{T_e + 2eV_i/K}$$

In case of hydrogen, helium and mercury vapour C_1 isof the order of 10^{-5} and 10^{-6} and (H/p) is of the order of 10^2 and hence as a first approximation C_1H^2/p^2 is smaller than 1 and $\log\left(1 + C_1H^2/p^2\right)^{1/2}$, $= \log\left(1 + \frac{C_1}{2}\cdot\frac{H^2}{p^2}\right)$

$$\approx \frac{C_1}{2}\cdot\frac{H^2}{p^2}$$

$$T_{eH} = T_e - \frac{T_e^2 C_1 H^2/p^2}{T_e + 2eV_i/K}$$

Then $$\frac{dT_{eH}}{dH} = -\frac{T_e^2 C_1 \cdot 2H/p^2}{T_e + 2eV_i/K}$$

and $$a = -\frac{T_e C_1}{T_e + 2eV_i/K}\cdot\frac{2H}{p^2}\left(\frac{U}{KT_e} - 1\right)$$

Then

$$H_{max} = \frac{-C_1 \pm \sqrt{C_1^2 - 16 C_1^3 \cdot \frac{T_e^2}{(T_e + 2eV_i/K)^2} \cdot \frac{H^2}{P^2}\left(\frac{U}{K T_e} - 1\right)^2}}{-4 \frac{T_e}{T_e + 2eV_i/K} C_1^2 \frac{H}{P^2}\left(\frac{U}{K T_e} - 1\right)}$$

Taking typical values for T_e, V_i & $\frac{H}{P}$ and U for hydrogen it can be shown that

$$C_1^2 \gg 16 C_1^3 \frac{T_e^2}{(T_e + 2eV_i/K)^2} \frac{H^2}{P^2}\left(\frac{U}{K T_e} - 1\right)^2$$

...(7.7).

and

$$H_{max} = \frac{P}{\sqrt{\frac{2 T_e}{(T_e + 2eV_i/K)} C_1 \left(\frac{U}{K T_e} - 1\right)}}$$

To verify the experimental data and to see whether the above deduced formula can explain the results numerical calculation has been carried out for each of the wavelength investigated. The values of electron temperature have been obtained from the experimental data published by Beckman (1948), the ionization potential and the energy of the upper level have been taken from Herzberg (1944) and C_1 values have been obtained from data obtained in the present investigation earlier. The results have been entered in Table 7.2.

TABLE - (7.2).

Gas	Wave length A°	Transition	Energy of the upper level U volts	V_i volts	T_e	C_1	H_{max} calculated	H_{max} calculated
Hydrogen	6562.73	n = 3 to n =2	12	13.595	20,000	2.4×10^{-5}	732	750
	4861.33	n = 4 to n =2	12.75	"	"		711	680
	4340.47	n = 5 to n =2	13	"	"		710	2460
	4101.74	n = 6 to n =2	13.65	"	"		750	2440
Helium	5875.67	$3D_3 \rightarrow 3P_2$	23	24.5	60,000	$.3\times10^{-5}$	2068	2140
	4471.48	$3D_4 \rightarrow 3P_2$	24	"	"	"	2102	2450
	6678.15	$1D_3 \longrightarrow 1P_2$	22.5	"	"	"	2204	2700
	5015.67	$1P_3 \longrightarrow 1S_2$	22.1	"	"	"	2310	3100
Mercury vapour	5790.65	$1D_2 \longrightarrow 1S_0$	9.3	10.4	10,000	4.7×10^{-5}	1200	1250
	4358.35	$3S_1 \longrightarrow 3P_1$	7.8	"	"	"	1790	1450
	5460.74	$3S_1 \rightarrow 3P_1$	7.8	"	"	"	1790	1690

with regard to ratio ($I_H)_{max}/I$ we see that from equation (7·5)

$$\frac{(I_H)_{max}}{I} = \left(1 + C_1 H^2/p^2\right)^{1/2} \frac{T_e}{T_{eH}} e^{-\frac{U}{K}\left(\frac{T_e - T_{eH}}{T_e T_{eH}}\right)}$$

$$\text{as} \quad T_{eH} = T_e - \frac{2T_e^2}{T_e + 2eV_i/K} \log\left(1 + C_1 H^2/p^2\right)^{1/2}$$

$$= T_e - \frac{T_e^2}{T_e + 2eV_i/K} \log\left(1 + C_1 H^2/p^2\right)$$

$$T_e\left[1 - \frac{T_e}{T_e + 2eV_i/K} \log\left(1 + C_1 H^2/p^2\right)\right]$$

Then

$$\frac{T_e}{T_{eH}} = \frac{1}{\left[1 - \frac{T_e}{T_e + 2eV_i/K}\log\left(1 + C_1 H^2/p^2\right)\right]}$$

and further $$e^{-\frac{U}{K}\left(\frac{T_e - T_{eH}}{T_e T_{eH}}\right)} = e^{-\frac{U T_e}{K T_e^2}\left(1 - \frac{T_{eH}}{T_e}\right)} = e^{-\frac{U}{K T_e}\left(1 - \frac{T_{eH}}{T_e}\right)}$$

Then

$$\frac{(I_H)_{max}}{(I)} = \left(1 + C_1 H^2/p^2\right)^{1/2} \frac{e^{-\frac{U}{K T_e}\left(1 - \frac{T_{eH}}{T_e}\right)}}{1 - \frac{T_e \log\left(1 + C_1 H^2/p^2\right)}{T_e + 2eV_i/K}}$$

The quantities on the R.H.S. are all known and the values have been entered in table (7.2). Taking the value of H_{max} as obtained from our calculation in case of individual line, values of $(I_H)_{max}/I$ have been calculated and the results entered in table 7.3.

TABLE – (7.3).

Gas	Wave length A°	H_{max} (gauss)	$\frac{(I_H)_{max}}{I}$ (Theo.)	$\frac{(I_H)_{max}}{I}$ (Expt.)
Hydrogen	6562.73	732	1.16	1.26
	4861.33	711	1.368	1.4
	4340.47	710	1.42	1.82
	4101.74	750	1.52	3.54
Helium	5875.87	2068	1.163	1.62
	4471.48	2102	1.143	2.54
	6678.15	2204	1.153	2.84
	5015.67	2301	1.123	3.19
Mercury vapour	5790.65	1200	1.632	2.04
	4358.35	1450	1.689	2.10
	5460.74	1790	1.689	2.60

Comparison of the experimental data with those derived from theoretical calculation above as is evident from table 7.1, 7.2 and 7.3 shows that agreement regarding the value of H_{max} the magnetic field at which the intensity is maximum is good specially in case of lines incase of helium and mercury vapour. In case of hydrogen and agreement is good in case of lines which originate from level nearer the ground level and wide disagreement is observed in case of lines which originate from higher level. In case of H_γ and H_δ lines the intensity is very low without magnetic field. But as the magnetic field is applied the intensity rapidly rises and is far more pronounced than in the case of H_α and H_β line. This evidently shows that the levels n = 3 and n = r are nearly saturated whereas levels n = 5 and n = 6 are sparsely populated but the number of electrons rapidly increased in these levels due to the action of the magnetic field. The exact solution can be obtained if a mathematical expression can be derived showing how these levels are populated when the magnetic field is present. The only effect of magnetic field that has been taken into consideration in the present investigation is the increase in the number of electrons due to increase of equivalent pressure and the loss of energy due to decrease of electrom temperature and as is well known the concept of equivalent pressure is of limited application specially for values of $(H/_p)$ smaller than 150 (gauss/mm. of pressure) and cannot be expected to hold in the region where the maximum is obtained i.e. $(H/_p) \approx 820$ gauss/mm. of Hg. in case of H_γ and H_δ line. Further the discrepancy in the theoretical and experimental values in case of helium and mercury vapour may be due to the fact whereas Maxwell Boltzman distribution law has been assumed in calculation it is established that for monotomic gases such as helium & mercury electron energy distribution is governed not by Maxwell Boltzman law but by Druyvestyn distribution. The same argument can be put forward with regard to the ratio $(I_H)_{max} / I$ as calculated.

Inspite of these limitations the calculation carried out above can represent the results to a certain approximation and the results can be better explained if a mathematical expression can be derived showing how the upper levels are populated in presence of magnetic field. The nature of the source of excitation has practically no noticeable effect upon the intensity distribution of spectral lines and its variation with magnetic field because the results obtained in the present investigation are in conformity with the results obtained by Kulkarni (1944) and Rokhlin (1939) where a d.c. source has been used for excitation. This further lends support to the observation made by Beck (1935) regarding the identical radiation property of both types of discharges.

A detailed mathematical theory can be provided when the data regarding the variation of intensity with discharge current, the pressure of the gas and the presence of other gases as impurities are available besides the data obtained here and a large number of spectral lines from different elements have been examined.

REFERENCES.

Beck. H. (1935) Z. Phys. 97, 355.

Beckman.L. (1948) Proc. Phys. Soc. 61 , 515.

Duttendack.O. and Kuppins.O. (1939) Phys. Rev. 55, 1199.

Fabrikant. V. and Rokhlin.G.N. (1938) C.R.Acad. Sci. USSR. 19, 393.

Fabrekant.V. and Rokhlin.G.N. (1939) J.expt. Theo. Phys. 9, 804.

Fowler.R. and Duttendack.O. (1949) Phys. Rev. 76 , 81.

Herzberg.G. (1944) Atomic Spectra and Atomic Structure. Dover Publications, New York.

Hodges.C. and Michels.L. (1928) Phys. Rev. 32, 913.

Kulkarni.S.B. (1944) Current Sci. 13 , 254.

Rokhlin.G.N. (1939) J.Phys. U.S.S.R. 1, 347.

Rossler.F. and Schonherr (1938). P (1938) Z.Tech. Phys. 19, 588.

Sen.S.N. and Gupta R.N. (1969) Ind. J. Pure. & Appl. Phys. 7, No. 7, 462.