CHAPTER III

DEPENDENCE OF THE INTENSITY OF MERCURY TRIPLET LINES ON DISCHARGE CURRENT AND TRANSVERSE MAGNETIC FIELD IN AN ARC PLASMA.

3.1. Introduction

The variation of the intensity of triplet series of mercury lines (λ 4047 Å, λ 4358 Å and λ 5461 Å) with discharge current varying from 2.5 A to 4.5 A and transverse magnetic field varying from zero to 1.6 KG has been investigated. The three main parameters upon whose variation the dependence of intensity of spectral lines depends are the pressure of the gas, discharge current and the magnetic field. Fowler and Duffendack (1949) studied the variation of intensity of some of the spectral lines of helium over the pressure range of 0.01 to 0.14 mm of mercury and it was observed that within this pressure range intensity is almost linearly dependent upon pressure. It was however, observed that the rate of increase of intensity with pressure depends upon the wavelength of radiation. However, for the pressure range of 3 mm to 70 mm of Hg each wavelength has its intensity maximum between 4 mm to 6 mm of Hg and then gradually decreases with pressure. It was further observed by the authors that the dependence of the intensity of spectral lines upon the tube current was linear over a current range of 1 mA to 100 mA for all types of transitions. Rocca, Fetzer and Collins (1981) found that the intensity of the spectral line λ 5143 Å from Ar II shows a linear variation with discharge current when the discharge current is varied upto 80 mA/cm^2.

The variation of intensity of spectral lines in magnetic field has been investigated earlier by Rokhlin (1939) in inhomogeneous magnetic field, by Forrest and Franklin (1966) and by Hedge and Ghose (1979) in longitudinal magnetic field, by Kulkarni (1944) and Sen, Das and Gupta (1972) in transverse magnetic field. The investigation of Sen et al (1972) was to study the variation of intensity of line spectra emitted from discharge tubes in hydrogen, helium and mercury in transverse magnetic field. It was found that in a transverse magnetic field the intensity of the lines increases with the increase of the magnetic field attaining a maximum value at a certain magnetic field and then gradually decreases. Sen et al (1972) also showed that the enhancement in intensity can be explained quantitatively as due to increase of electron temperature and decrease of azimuthal electron density caused by the presence of transverse magnetic field. It was further shown that the field at which the line intensity becomes a maximum is a function of the energy of the upper level. It is also worthwhile to investigate whether the physical processes undergo any significant change when transition takes place from glow to arc region. Sadhya and Sen (1980) studied the variation of current and voltage in a mercury arc plasma as well as the variation of electron temperature in axial magnetic field, the electron temperature having been determined by a spectroscopic method.

In order to investigate the phenomena in greater detail the enhancement of the intensity of the spectral lines of the sharp series triplet radiations of mercury $7^3S_1 \longrightarrow 6^3P_{012}$ corresponding to radiations λ 4047 Å, λ 4358 Å and λ 5461 Å in presence of a longitudinal magnetic field between zero and 2000 gauss has been investigated by Sen and Sadhya (1986). The effect of the magnetic field was found to be different as regards the variation of intensity and occurance of maxima in the three lines. These variations were explained by considering the reabsorption of the emission lines. A mathematical theory has been presented and the theoretical deductions are in good agreement with experimental results.

Rocca, Fowler and Collins (1981) studied in an axial magnetic field the variation of intensity of the spectral lines λ4145.3 Å of Ar II and λ 5916.6 Å of Ag I in a hollow cathode discharge. It was observed that for λ 5143.3 Å for small discharge current (9 mA/cm^2) there was practically no change in intensity even for a field of 800 G. As the current is gradually increased the intensity falls specially for high values of magnetic field and for a discharge current of 76.5 mA/cm^2 the intensity falls to half its value at zero magnetic field. In case of λ 5916.6 Å there is practically no change of intensity even for a field of 800 G.

It is thus evident from the above resume that the intensity of the spectral lines is sensitive to the change of pressure, discharge current and the external magnetic field and not only there is variation in the intensity profiles of spectral lines of different elements but there is variation among the spectral lines of the same element. It is therefore evident that the phenomena should be investigated in greater detail with a different alignement of magnetic field. Consequently in the present study we have investigated the variation of intensity of spectral lines of the triplet series of mercury in an arc plasma with the variation of the arc current and also in a variable transverse magnetic field.

3.2. EXPERIMENTAL SET-UP

In the present investigation, the intensities of the sharp series triplet lines of the mercury atom were investigated with variation of (i) arc current and (ii) transverse magnetic field. The source of radiation is a mercury arc constructed of pyrex tube (0.75 cm internal radius, 8.0 cm in length) and was force cooled externally. The buffer gas was dry air whose concentration was regulated through a needle valve. Radiations from the axial region of the positive column of the arc discharge were focussed by lens arrangement on the slit (width 0.5 mm) of an accurately calibrated constant deviation spectrograph. The detailed experimental arrangement has been given in Chap. II. The triplet radiations λ 5461 Å, λ 4358 Å and λ 4047 Å were focussed separately on the cathode of the photomultiplier (M. 10. F.S.29 V_λ) and the intensities of the lines were recorded. Details of experimental arrangement and the technique for measuring the intensities of spectral lines employing electronic circuits have been reported earlier (Sen et al, 1972) and given in Chap. II. It was established by separate set of experiments (Sen et. al, 1972) that the readings recorded in the microammeter of the output electronic circuit were always proportional to the intensities of the spectral lines within the range of wavelengths investigated. In the first set of experiments the intensities of the spectral lines have been measured for five values of arc current (2.5 A, 3.0 A, 3.5 A, 4.0 A, and 4.5 A). In the second set of experiments the intensities of the spectral lines have been measured when the arc has been placed in a transverse magnetic field and the field varied between zero to 1.6 KG. The intensity measurements in magnetic field have been obtained for all the three lines for three values of arc current (3.0 A, 3.5 A, and 4.0 A). The pressure within the discharge tube was kept at 0.05 torr.

3.3. RESULTS AND DISCUSSIONS

The variation of the intensities of spectral lines (λ 4047 Å $7^3S_1 \longrightarrow 6^3P_0$, λ 4358 Å $7^3S_1 \longrightarrow 6^3P_1$, λ 5461 Å $7^3S_1 \longrightarrow 6^3P_2$) has been investigated for
(i) discharge current varying from 2.5 A to 4.5 A, and
(ii) for magnetic field varying from zero to 1.6 KG. Each spectral line has been investigated for three arc currents namely 3 A, 3.5 A, and 4.0 A.

Variation of spectral intensity with arc current:

(a) It is noted (Fig. 3.1) that the intensities of all the spectral lines investigated increase linearly with arc current as has been observed previously by Fowler and Duffendack (1949) in case of helium and also by Rocca, Fetzer and Collins (1981) in case of argon. It is however, observed that the rate of increase of intensity with current is different for the three spectral lines. From the curve (Fig. 3.1) it has been calculated that for λ 4047 Å $\frac{dI}{di}$ = 0.20, for λ 4358 Å $\frac{dI}{di}$ = 0.245 and for λ 5461 Å $\frac{dI}{di}$ = 0.31 where I is the spectral line intensity and i is the arc current. To explain the observed results we note that the intensity of a spectral line is given by

$$I = n \frac{g_u}{Z_o} A_{u\ell} h \nu_{u\ell} \exp\left[-\frac{(E_u - E_\ell)}{KT_e}\right] \qquad (3.1)$$

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. E_u and E_ℓ are the energies of the upper and lower levels between which transition takes place, $A_{u\ell}$ is the Einstein coefficient of transitional probability and $\nu_{u\ell}$ is the frequency of emitted radiation. It is evident that all the terms except the electron density n and electron temperature T_e are independent of current flowing through the arc tube. With regard to variation of electron temperature with arc current, it can be noted

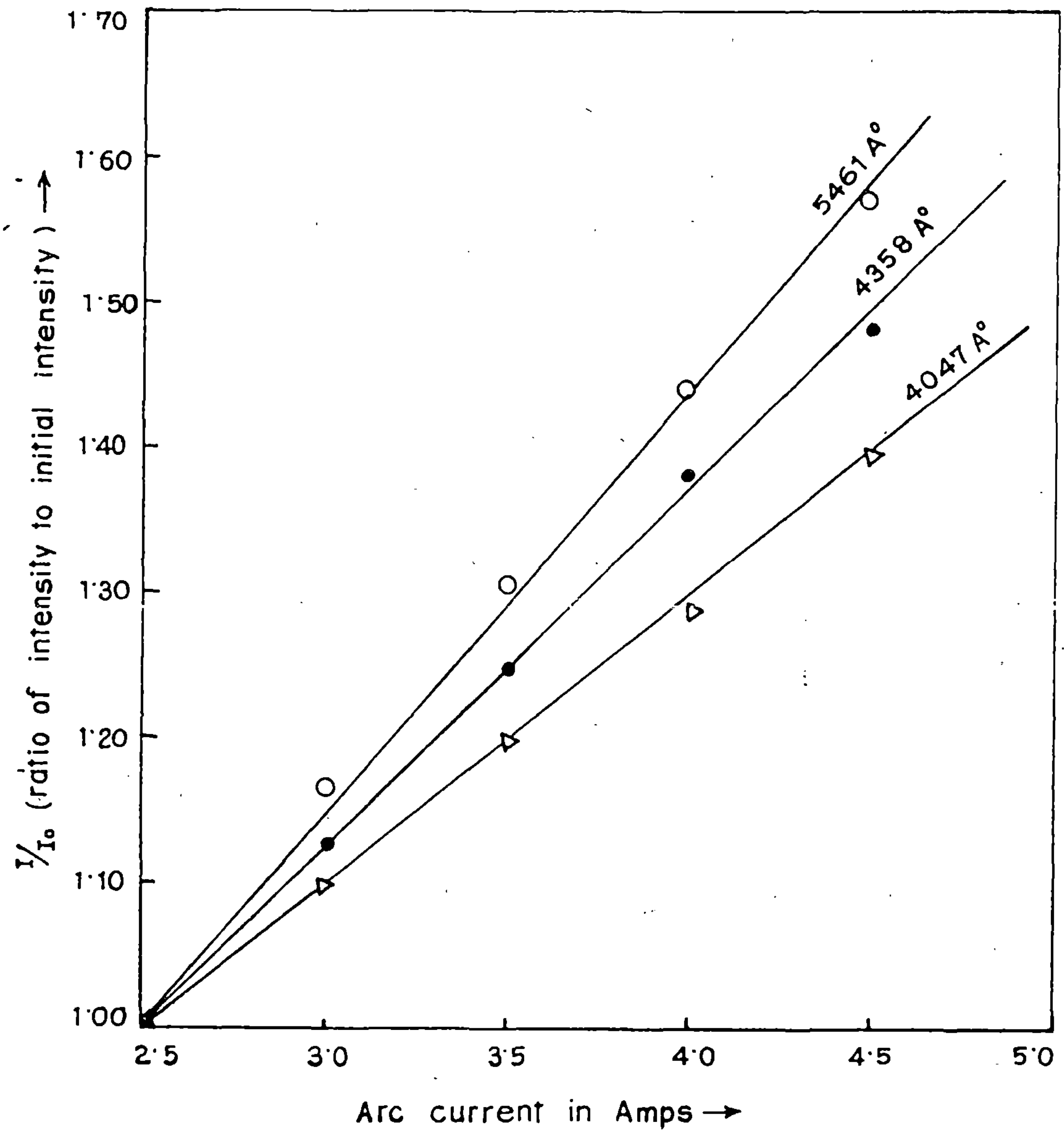

1·70
1·60
1·50
1·40
1·30
1·20
1·10
1·00
I/Io (ratio of intensity to initial intensity) →
2·5
3·0
3·5
4·0
4·5
5·0
Arc current in Amps →
5461 A°
4358 A°
4047 A°

Fig.3·1.

that an independent experiment (Chap. V) was performed in which the voltage across the arc was measured for three arc currents 3 A, 4 A and 5 A. In each case it was found that the voltage across the arc remained constant at 15.25 volts. The electron temperature is given by

$$KT_e = \frac{\sqrt{2}}{3}\,\frac{1}{R^{1/2}}\,eL\left[E/p\right] \qquad \text{von-Engel(1965)} \qquad (3.2)$$

where K is the Boltzmann constant, R fractional of energy lost by the electron in collision with an atom, L is the mean free path of the electron at a pressure of 1.0 torr, which are independent of current and as the voltage across the arc is constant so that longitudinal field E remains constant and it can be concluded that the electron temperature is independent of arc current at least within the range of current here investigated.

In order to study the variation of intensity with current it is noted that in Fig. (3.1) the variation of $I_a/I_{2.5}$ where I_a is the intensity at any discharge current and $I_{2.5}$ is the intensity at 2.5 A has been plotted against the discharge current for all the three lines. Hence from eqn. (3.1) we get

$$\frac{I_a}{I_{2.5}} = \frac{n_a\, g_u/Z_0}{n_{2.5}\, g_u/Z_0}\;\frac{A_{ul}\,h\nu_{ul}\exp\left(-\frac{E_u-E_l}{KT_e}\right)}{A_{ul}\,h\nu_{ul}\exp\left(-\frac{E_u-E_l}{KT_e}\right)}$$

$$= \frac{n_a}{n_{2.5}} \qquad (3.3)$$

Langmuir (1925) has shown that the current in an arc is given by

$$i = 5.76 \times 10^{-10} \frac{n_a \lambda_e}{T_e^{1/2}} E \qquad (3.4)$$

where λ_e is the mean free path at 1.0 torr and other symbols have their usual significance. Hence from eqns. (3.3) and (3.4)

$$\frac{I_a}{i I_{2.5}} = \frac{\sqrt{T_e}}{5.76 \times 10^{-10} \lambda_e E n_{2.5}}$$

Putting the value of T_e from eqn. (3.2)

$$\frac{1}{i} \frac{I_a}{I_{2.5}} = \frac{2^{1/4} e^{1/2} L^{1/2} E^{1/2}}{3^{1/2} R^{1/4} K^{1/2} p^{1/2} \times 5.76 \times 10^{-10} \lambda_e E n_{2.5}}$$

$$= \frac{2^{1/4} e^{1/2} L^{1/2} E^{1/2} P}{3^{1/2} R^{1/4} K^{1/2} p^{1/2} \times 5.76 \times 10^{-10} L E n_{2.5}}$$

$$= \frac{c}{n_{2.5}}$$

where c is a constant.

From this analysis it is evident that the rate of variation of intensity of all spectral lines with arc current should be same whereas from the experimental results the rate of increase of intensity is highest for λ 5461 Å and lowest for λ 4047 Å while that for λ 4358 Å lies in between.

(b) Intensity variation with magnetic field:

Almost similar nature of results have been obtained in case of three spectral lines investigated when the arc is placed in a transverse magnetic field, (Fig. 3.2, 3.3 and 3.4). The enhancement of intensity is noticed in case of all the spectral lines when the transverse magnetic field is present in conformity with results obtained earlier in case of glow discharge (Sen, Das and Gupta, 1972). But in the present investigation in case of arcs a noteworthy feature is that below a certain value of magnetic field a minimum in intensity is observed and the magnetic field at which this minimum occurs differs though by a small amount in case of all three spectral lines investigated,

A factor which has not been taken into consideration here so far is that self absorption plays a dominant role in the intensity profiles of these lines. In a recent paper (Sen and Sadhya, 1986) of this laboratory it was observed that in a longitudinal magnetic field the variation of intensity of the triplet lines of mercury is different from one another and also the maximum intensity for the three lines occurs at different magnetic field values. These variations have been explained by considering the reabsorption of the spectral lines and the mathematical theory developed had explained quantitatively the observed experimental results.

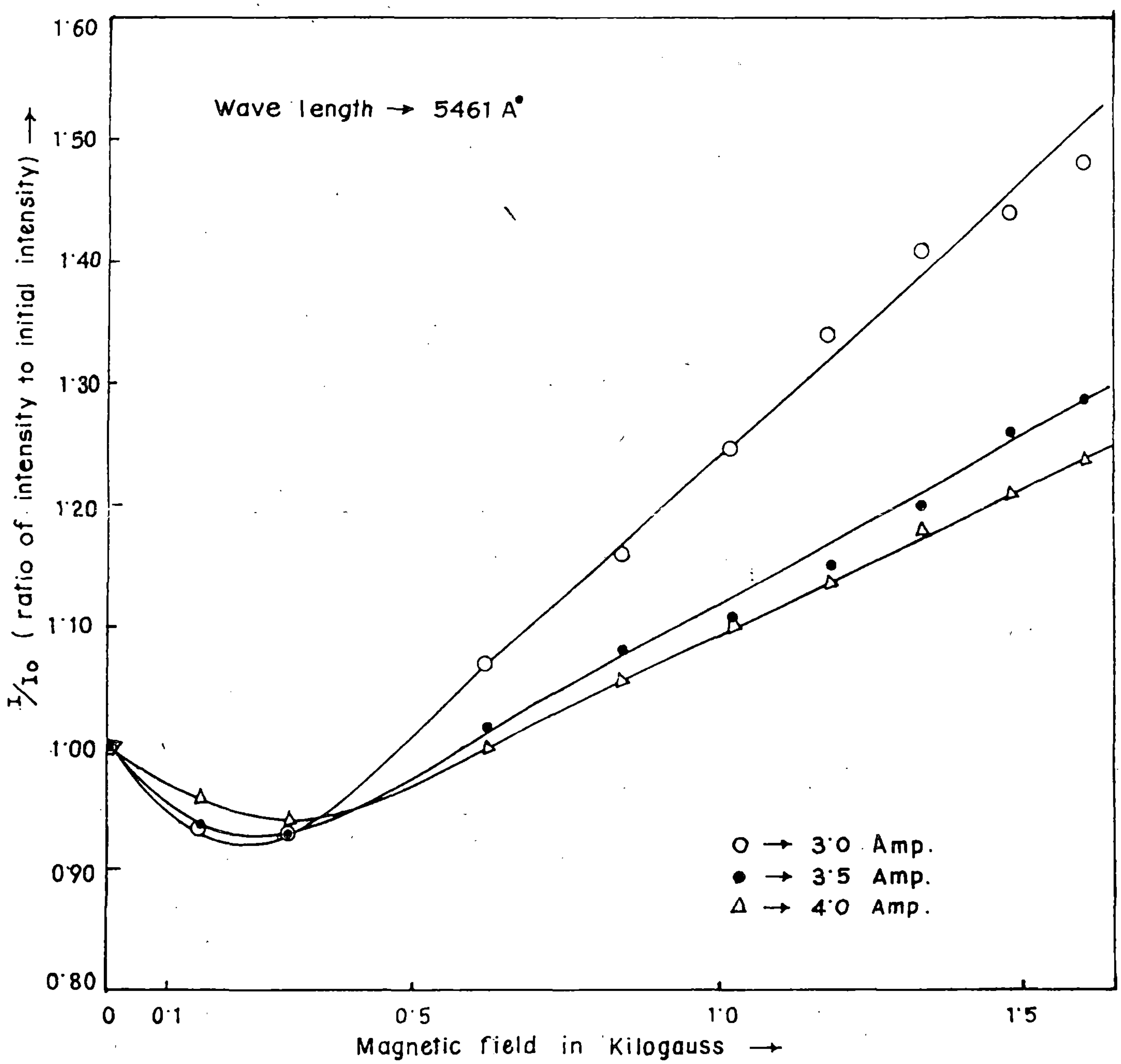
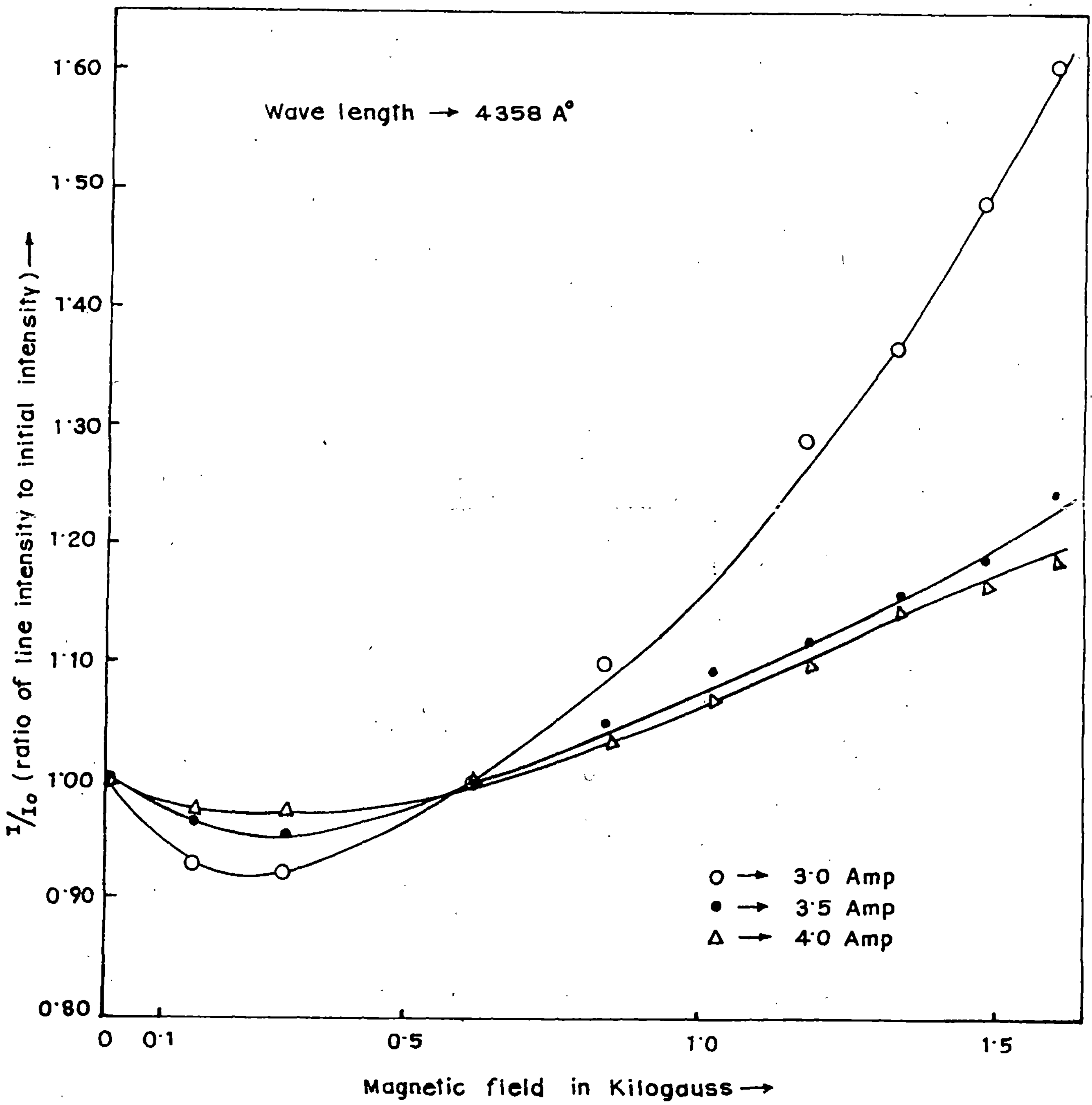

Wave length → 5461 A°
I/Io (ratio of intensity to initial intensity) →
1·60
1·50
1·40
1·30
1·20
1·10
1·00
0·90
0·80
0
0·1
0·5
1·0
1·5
Magnetic field in Kilogauss →
O → 3·0 Amp.
● → 3·5 Amp.
Δ → 4·0 Amp.

Fig.3·2.



Wave length → 4358 A°
I/I_o (ratio of line intensity to initial intensity) →
1·60
1·50
1·40
1·30
1·20
1·10
1·00
0·90
0·80
0
0·1
0·5
1·0
1·5
O → 3·0 Amp
● → 3·5 Amp
Δ → 4·0 Amp
Magnetic field in Kilogauss →

Fig. 3.3

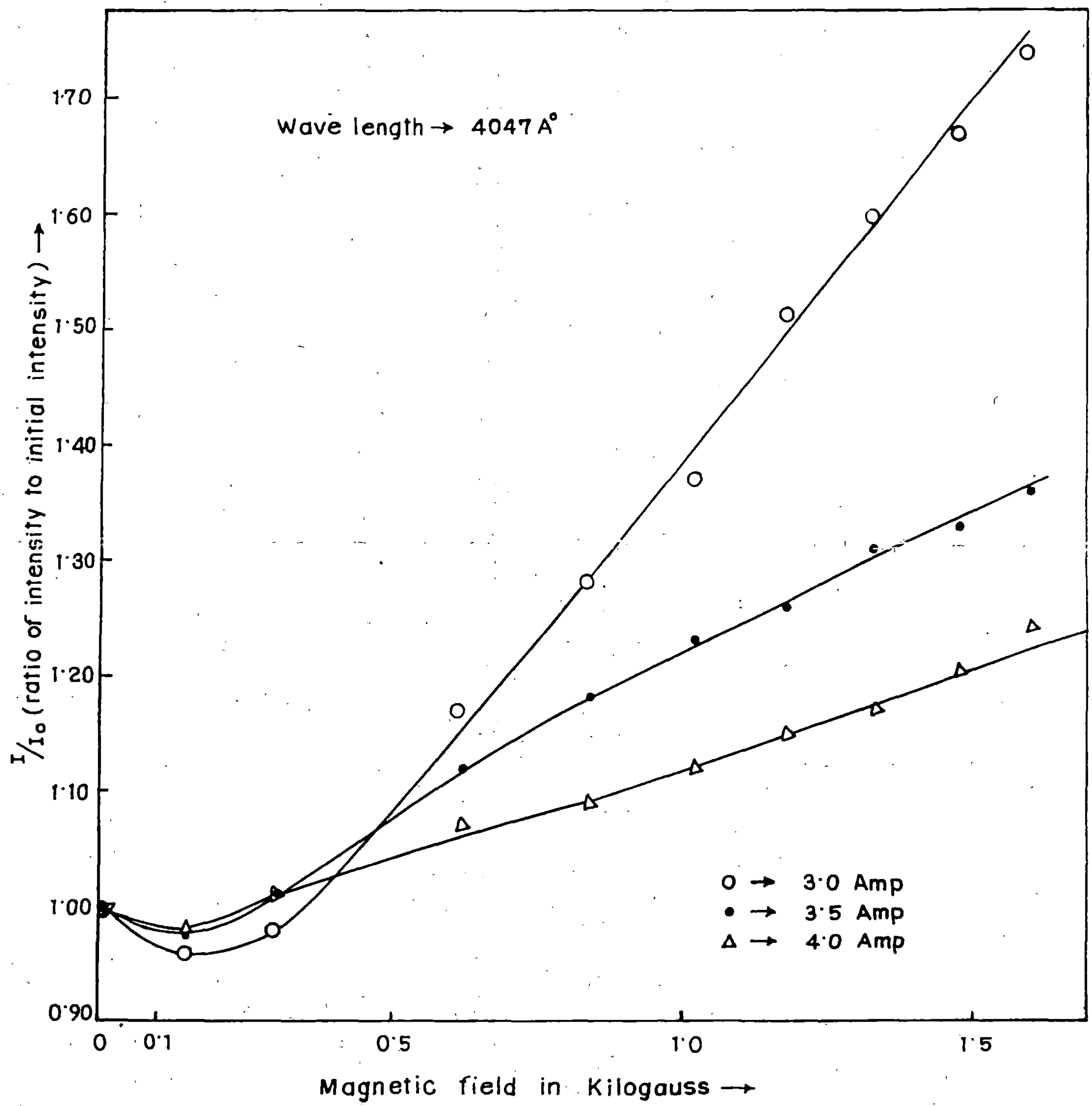

Wave length → 4047 A°
$^{I}/_{I_o}$ (ratio of intensity to initial intensity) →
1·70
1·60
1·50
1·40
1·30
1·20
1·10
1·00
0·90
0
0·1
0·5
1·0
1·5
Magnetic field in Kilogauss →
O → 3·0 Amp
● → 3·5 Amp
Δ → 4·0 Amp

Fig.3·4.

To explain the rate of variation of intensity of the mercury triplet lines with arc current as has been observed by Sen and Sadhya (1986) we assume

$$I_{u\ell} = (1 - A_S) I^0_{u\ell} \qquad (3.5)$$

Sen and Sadhya (1986)

where A_S is the self absorption of the spectral line and $I^0_{u\ell}$ is the intensity of the spectral line without self absorption and

$$I^0_{u\ell} = n \frac{g_u}{Z_i} A_{u\ell} h \nu_{u\ell} \exp\left[-\frac{(E_u - E_\ell)}{K T_e}\right]$$

and

$$A_S = f_{\ell u} \lambda_{u\ell} \rho n_\ell(0) \qquad (3.6)$$

where $f_{\ell u}$ is the absorption oscillator strength, $\lambda_{u\ell}$ is the wavelength of the radiation,

$$\rho = \frac{1}{3} \pi r_0 C \left[\frac{M}{2\pi K T_g}\right]^{1/2} R \qquad (3.7)$$

and $n_\ell(0)$ population density at the axis of the discharge tube which is the same for all the three spectral lines. Equations (3.5), (3.6) and (3.7) have been deduced in the earlier paper (Sen and Sadhya, 1986) and given in the review article. If as before, $I_{2.5}$ denotes the intensity of the spectral line at the initial current of 2.5 A, then

$$\frac{I_{u\ell}}{I_{2.5}} = \frac{(1 - A_s)_i}{(1 - A_s)_{2.5}}$$

$$= \left\{ 1 - f_{\ell u} \lambda_{u\ell} \frac{1}{3} \pi r_0 C \frac{n_1(0) M^{1/2} R}{(2\pi K T_g)^{1/2}} \right\} \bar{C}$$

where $(1 - A_s)_{2.5}$ can be regarded as constant and represented by $\frac{1}{\bar{C}}$ then

$$\frac{d}{di}\left(\frac{I_{u\ell}}{I_{2.5}}\right) = \frac{d}{di}\left[\bar{C} - \bar{C}\alpha T_g^{-1/2}\right]$$

where $\alpha = f_{\ell u} \lambda_{u\ell} \frac{1}{3} \pi r_0 C \frac{n_1(0) M^{1/2} R}{(2\pi K)^{1/2}}$

as no other term except T_g is a function of the arc current, now

$$\frac{d}{di}\left[\bar{C} - \bar{C}\alpha T_g^{-1/2}\right] = \frac{\bar{C}\alpha}{T_g^{3/2}} \frac{dT_g}{di}$$

We thus observe that as $\frac{dT_g}{di}$ will be the same for the three spectral lines investigated the rate of variation of intensity with current will depend upon the value of α. From the expression used for α it is further evident that for the three spectral lines all terms except $f_{\ell u}$ and $\lambda_{u\ell}$ are constants and hence $\frac{d}{di}\left(I_i / I_{2.5}\right)$ will be proportional to $\lambda_{u\ell} f_{\ell u}$. Hence we can write

$$\frac{d}{di}\left(\frac{I_{ul}}{I_{2.5}}\right)_{4047} : \frac{d}{di}\left(\frac{I_{ul}}{I_{2.5}}\right)_{4358} : \frac{d}{di}\left(\frac{I_{ul}}{I_{2.5}}\right)_{5461}$$

$$\equiv (f_{lu}\lambda_{ul})_{4047} : (f_{lu}\lambda_{ul})_{4358} : (f_{lu}\lambda_{ul})_{5461}$$

The values of f_{lu} as provided by Gruzdev (1967) are as follows:

$$(f_{lu})_{4047} = 0.10 \quad (f_{lu})_{4356} = 0.11 \quad (f_{lu})_{5461} = 0.14.$$

Hence

$$(f_{lu}\lambda_{ul})_{4077} : (f_{lu}\lambda_{ul})_{4358} : (f_{lu}\lambda_{ul})_{5461}$$

$$\equiv 0.2 : 0.24 : 0.38.$$

whereas from our experimental data the ratio is in the ratio 0.200: 0.245: 0.310. Thus we observe that there is perfect agreement between theoretical and experimental results for the spectral lines λ 4047 Å and λ 4358 Å but there is some discripancy with regard to the line λ 5461 Å.

With regard to increase of intensity with the application of magnetic field the results are consistent with all previous observations (Sen, Das and Gupta, 1972; Sadhya and Sen, 1980) and the enhancement of intensity has been explained on the observation that the electron temperature increases and electron density decreases in a transverse magnetic field whereas the reverse process takes place when the field is longitudinal. Based on these postulates analytical expressions have been deduced which explain satisfactorily the observed experimental results. In the present investigation however, a minimum in the intensity magnetic field variation curve has been noted in case of all the three spectral lines investigated.

We can now introduce the effect of self-absorption to see how the intensity of lines changes due to self-absorption in a transverse magnetic field, it has been deduced in the paper (Sen and Sadhya, 1986) and also given in the review article that

$$\frac{(I_{u\ell})_H}{I_{u\ell}} = 1 - f_{\ell u} \lambda_{u\ell}\, \rho \left\{ n_\ell(0)_H - n_\ell(0) \right\} \left\{ \frac{n_u(0)_H}{n_u(0)} \right\} \tag{3.8}$$

where $f_{\ell u}$ is the absorption oscillator strength, $\lambda_{u\ell}$ is the wavelength of radiation

$$\rho = \frac{1}{3} \pi r_0 C \left[\frac{M}{2\pi K T_g} \right]^{1/2} R$$

r_0 is the classical electron radius and C is the velocity of light and other symbols have their usual significance. When a transverse magnetic field is present it has been deduced by Sen and Das (1973) that if n_H and n_0 are the electron density in presence and in absence of magnetic field, then

$$n_H = n_0 \exp(-aH)$$

where

$$a = \frac{eEC_1^{1/2} r}{2kT_e P}$$

where E is the axial electric field, $C_1 = \left(\frac{e}{m}\frac{L}{v_r}\right)^2$ where L is the mean free path of the electron at a pressure of 1.0 torr, v_r is the random velocity and r is the distance from the axis at which the electron density is n_H. Then we can write

$$n_l(0)_H = n_l(0) \exp(-aH)$$

$$n_u(0)_H = n_u(0) \exp(-aH)$$

we assume that electron density in both the upper and lower levels are affected in the same way. Hence from eqn. (3.8) we get

$$\begin{aligned}\frac{(I_{ul})_H}{I_{ul}} &= 1 - f_{lu}\lambda_{ul}\rho\, n_l(0)\left\{\exp(-aH) - 1\right\}\exp(-aH)\\ &= 1 - f_{lu}\lambda_{ul}\rho\, n_l(0)\left\{\exp(-2aH) - \exp(-aH)\right\}\\ &= 1 - \alpha\exp(-2aH) + \alpha\exp(-aH)\end{aligned} \qquad (3.9)$$

where $\alpha = f_{lu}\lambda_{ul}\rho\, n_l(0)$

then we get from eqn. (3.9)

$$\frac{d}{dH}\frac{(I_{ul})_H}{I_{ul}} = 2\alpha a \exp(-2aH) - \alpha a \exp(-aH) = 0.$$

or

$$H_{min} = \frac{\log_e 2}{a} \qquad (3.10)$$

From the experimental results it is evident that a minimum in the intensity magnetic field variation curve is observed in case of all the three spectral lines and the minimum occurs in the range of 200 to 250 gauss.

The numerical value of "a" has been obtained from measured data. The electric field per unit length in the mercury arc as measured is 1.6 volts/cm, C_1 is the square of mobility of the electron in mercury vapour at a pressure of 1.0 torr and has been taken as 2×10^{-6} by McDaniel(1964). The value of T_e has been taken to be 25000°K after Karelina (1942) and confirmed by Sadhya (1982) in this laboratory by a spectroscopic method. The inside pressure has been measured to be 0.05 torr and a reasonable value of r has been taken as 0.333 cm and the computed value of "a" is found to be 3.496×10^{-3}. From eqn. (3.10) it is found that a minimum in the value of intensity magnetic field variation curve can be expected to occur around 201.4G. This is consistent with the experimental results obtained in the case of three spectral lines and in the intensity-magnetic field variation curve a minimum is found to occur between 200 to 250 gauss.

The quantitative agreement between the theoretical results and experimental observation should not be over exphasized because there is some uncertainty in the calculated value of "a" but the agreement between the orders of magnitude between the theoretical and experimental results should be regarded as a definite proof that self-absorption plays a definite role with regard to intensity variation with respect to the arc current as well as with magnetic field.

Another noteworthy feature of the observed experimental results which is evident from Fig. (3.2), (3.3) and (3.4) is that in case of all spectral lines the increase of intensity in presence of magnetic field is greater for the lowest arc current and the effect becomes less and less as the arc current is gradually increased. From equation (3.9) we get

$$\frac{(I_{u\ell})_H}{I_{u\ell}} = 1 - f_{\ell u}\lambda_{u\ell}\rho\, n_\ell(0)\left\{\exp(-2aH) - \exp(-aH)\right\}$$

It is thus evident that for a particular spectral line $f_{\ell u}$, $\lambda_{u\ell}$, ρ and a are constants and the intensity becomes for a certain value of H a function of the axial electron density. From the above equation it is clear that as $n_\ell(0)$ decreases that is the current decreases $(I_{u\ell})_H$ will increase which is consistent with experimental observation.

In the earlier paper (Sen and Sadhya,1986) as well as in the present investigation the role of self-absorption in the emission spectrum of the mercury triplet series of lines has been brought out, specially its effect on the variation of intensities of the lines when the arc current and the external magnetic field are varied.

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Dependence of Intensity of Mercury Triplet Lines on Discharge Current & Transverse Magnetic Field in an Arc Plasma

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The variation of the intensity of triplet series of mercury lines (λ4047 Å, λ4358 Å and λ5461 Å) with the discharge current varying from 2.5 to 5 A and the transverse magnetic field varying from zero to 1.6 kG, has been investigated experimentally in an arc plasma. It has been observed that the intensity increases linearly with discharge current but the rate of increase is different for the three spectral lines. The intensity also increases in the presence of transverse magnetic field but all the three lines show a minimum around the magnetic field range 200-250 G. The effect of magnetic field is more prominent for smaller values of arc current. Utilizing the interpretation of the effect of self-absorption on the intensity of spectral lines, as has been proposed by S N Sen and S K Sadhya [*Pramāna (India)*, **26** (1986) 205], all the observed experimental results can be satisfactorily explained.

1 Introduction

The dependence of intensity of spectral lines has been investigated with the variation of three main parameters, viz the pressure of the gas, discharge current and the magnetic field. Fowler and Duffendack[1] investigated the variation of intensity of some of the spectral lines of helium over the pressure range of 0.01-0.14 mm of mercury and discharge current varying from 1 mA to 100 mA. Rocca *et al.*[2] observed the variation of intensity of the spectral line λ5143 Å from Ar II with discharge current. The variation with magnetic field has been investigated earlier by Rokhlin[3] in inhomogeneous magnetic fields; by Forrest and Franklin[4] and by Hedge and Ghosh[5] in longitudinal magnetic field; by Kulkarni[6], Sen *et al.*[7] in transverse magnetic field. Sadhya and Sen[8] investigated the intensity variation with current and voltage across a mercury arc plasma as well as the variation of electron temperature in a longitudinal magnetic field. In order to investigate the phenomena in greater detail, the enhancement of the intensity of the spectral lines of the sharp series triplet radiations of mercury [$T^3S_1 \rightarrow \sigma^3P_{012}$], corresponding to radiations λ4047 Å, λ4358 Å and λ5461 Å, in presence of a longitudinal magnetic field between 0 and 2000 G has been investigated by Sen and Sadhya[9]. The effect of the magnetic field was found to be different as regards the variation of intensity and occurrence of maxima in the three lines. These variations were explained by considering the reabsorption of the emission lines. It is thus evident from the above resume that the intensity of the spectral lines is sensitive to the change of pressure, discharge current and the external magnetic field; not only there is variation in the intensity profiles of spectral lines of different elements but there is variation among the spectral lines of the same element. Hence it is necessary that the phenomena should be investigated in greater detail with a different alignment of magnetic field. Consequently, in the present investigation we have studied the variation of intensity of spectral lines of the triplet series of mercury in an arc plasma with the variation of the arc current and also in a variable transverse magnetic field.

2 Experimental Set-up

The source of radiation was a mercury arc constructed of pyrex tube (0.75 cm internal radius, 8 cm length) and was force cooled externally. The buffer gas was dry air the concentration of which was regulated through a neeedle valve. Radiations from the axial region of the positive column of the arc discharge were focussed, by lens arrangements, on the slit (width 0.5 mm) of an accurately calibrated constant deviation spectrograph. The triplet radiations λ5461 Å, λ4358 Å and λ4047 Å were focussed separately on the cathode of the photomultiplier (M.10 F.S. 29 V_λ) and the intensities of the lines were recorded. Details of experimental arrangement and the technique for measuring the intensities of spectral lines employing electronic circuits have been reported earlier[7]. It was established by separate set of experiments (Sen *et al.*[7]) that the readings recorded in the microammeter of the output electronic circuit were always proportional to the intensities of the spectral lines within the range of wavelengths investigated. In the first set of experiments, the intensities of the spectral lines were measured for five values of discharge current (2.5, 3.0, 3.5, 4.0 and 4.5 A). In the second set of experiments, the intensities of the spectral lines were measured when the arc has been placed in a transverse magnetic field and the field varied between zero and 1.6 kG. The intensity measurements in magnetic field were taken for all the three lines for three values of arc current (3.0, 3.5 and 4 A). The pressure within the discharge tube was kept at 0.05 Torr.

3 Results and Discussion

3.1 Intensity Variation with Arc Current

It is noted (Fig. 1) that the intensities of all the spectral lines investigated increase linearly with arc current as has been observed previously by Fowler and Duffendack[1] in case of helium and also by Rocca *et al.*[2] in case of argon. It is however observed that the rate of increase of intensity with current is different for the three spectral lines. From the curves in Fig. I, it has been calculated that for $\lambda 4047$ Å, $dI/di = 0.2$; for $\lambda 4358$ Å, $dI/di = 0.245$; and for $\lambda 5461$ Å, $dI/di = 0.31$; where I is the spectral intensity and i the arc current. To explain the observed results, we note that the intensity of a spectral line is given by

$$I = n \cdot \frac{g_u}{Z_0} A_{ul} h \nu_{ul} \exp\left[\frac{-(E_u - E_l)}{KT_e}\right] \qquad \ldots(1)$$

where n is the electron density per unit volume, Z_0 the internal partition function, g_u the statistical weight of the upper level. E_u and E_l are the energies of the upper and lower levels between which transition takes place, A_{ul} is the Einstein coefficient of transitional probability and ν_{ul} is the frequency of emitted radiation. It is evident that all the terms except r and the electron temperature (T_e) are independent of current flowing through the arc tube. With regard to variation of T_e with i, it may be noted that an independent experiment was performed in which the voltage across the arc was measured for three arc currents, viz. 3, 4 and 5 A. In each case, it was found that the voltage across the arc remained constant at 15.25 V. The electron temperature is given by[10]

$$kT_e = \frac{\sqrt{2}}{3} \frac{1}{\kappa^{1/2}} eL\left(\frac{E}{P}\right) \qquad \ldots(2)$$

where k is the Boltzmann constant, κ the fraction of energy lost by the electron in collision with an atom, L the mean free path of the electron at a pressure of 1 Torr, and these terms are independent of current. As the voltage across the arc is constant, the longitudinal field E remains constant and it can be concluded that the electron temperature is independent of arc current at least within the range of currents investigated in the present study.

In order to investigate the variation of intensity with current, it is noted that in Fig. 1 the variation of $I_a/I_{2.5}$ where I_a is the intensity at any discharge current and $I_{2.5}$ is the intensity at current 2.5 A, has been plotted against the discharge current, for all the three spectral lines. Hence from Eq. (1) we get

$$\frac{I_a}{I_{2.5}} = \frac{n_a}{n_{2.5}} \qquad \ldots(3)$$

Langmuir[11] has shown that the current in an arc is given by

$$i = 5.76 \times 10^{-10} \frac{n_e \lambda_e}{T_e^{1/2}} E \qquad \ldots(4)$$

where λ_e is the mean free path at 1 Torr and other symbols have their usual significance. Hence from Eqs (3) and (4)

$$\frac{I_a}{I_{2.5}} = \frac{C}{n_{2.5}}$$

where C is a constant and $n_{2.5}$ is the electron density for the arc current of 2.5 A. From this analysis it is evident that the rate of variation of intensity of all spectral lines with arc current should be same whereas from the experimental results the rate of increase of intensity is highest for $\lambda 5461$ Å and lowest for $\lambda 4047$ Å while that for $\lambda 4358$ Å, it lies in between.

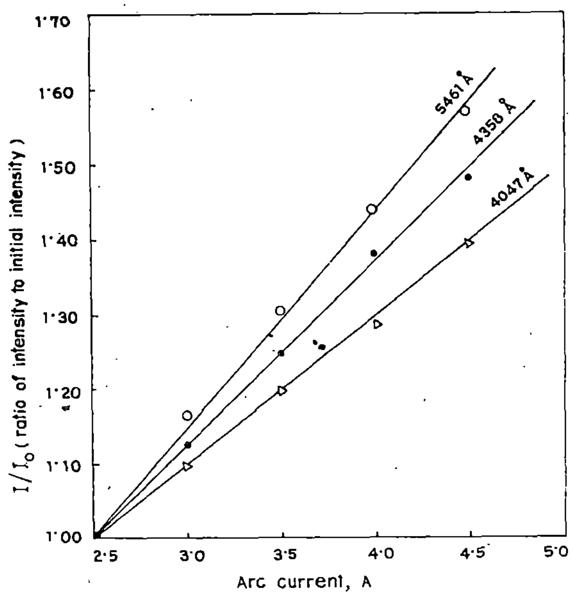

Fig. 1 — Variation of I/I_0 with arc current for $\lambda 4047$ Å, $\lambda 4358$ Å and $\lambda 5461$ Å

3.2 Intensity Variation with Magnetic Field

Almost similar results have been obtained in case of the three spectral lines investigated when the arc is placed in a transverse magnetic field (Figs 2-4). The enhancement of intensity is noticed in case of all the spectral lines when the transverse magnetic field is present in conformity with the results obtained earlier in case of glow discharge (Sen *et al.*[7]). But in the present investigation in case of arcs a noteworthy feature

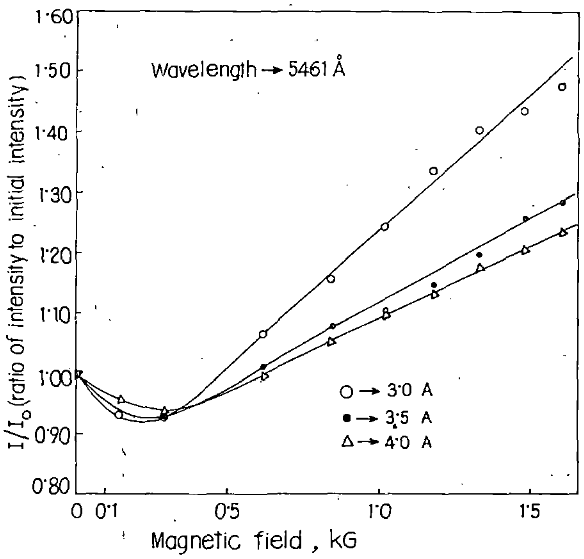

Fig. 2—Variation of I/I_0 with magnetic field (λ5461Å)

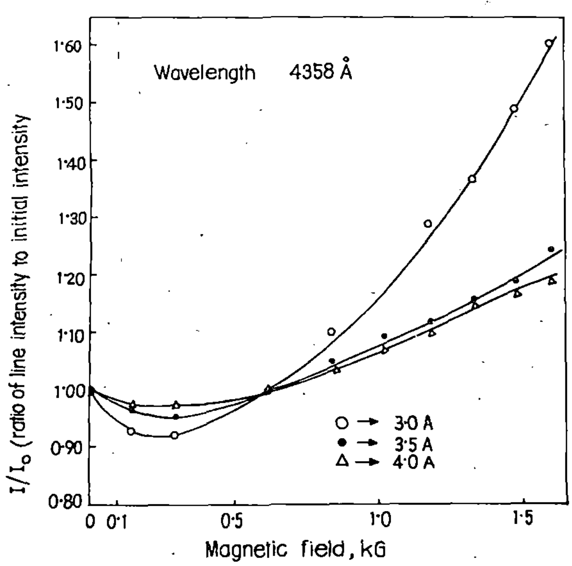

Fig. 3—Variation of I/I_0 with magnetic field (λ4358Å)

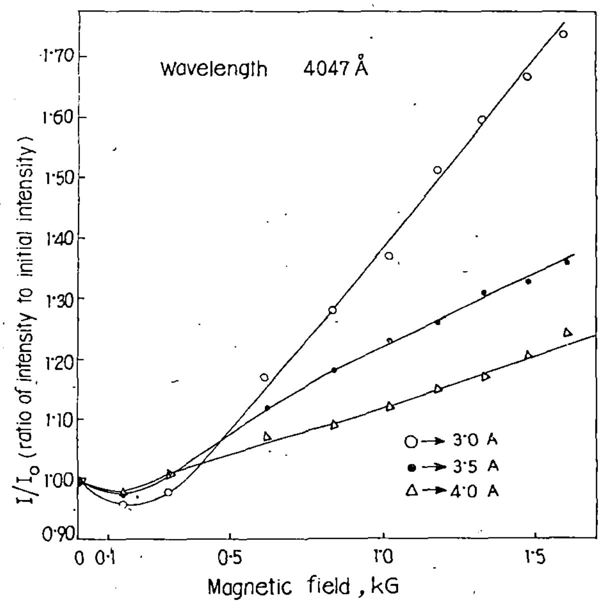

Fig. 4—Variation of I/I_0 with magnetic field (λ4047Å)

is that below a certain value of magnetic field a minimum in intensity is observed and the magnetic field at which this minimum occurs differs, though by a small amount, in case of all the three spectral lines investigated.

A factor which has not been taken into consideration here so far is that self-absorption plays a dominant role in the intensity profiles of these lines. In a recent paper[9], it was observed that in a longitudinal magnetic field the variation of intensity of the triplet lines of mercury is different from one another and also the maximum intensity for the three lines occurs at different magnetic field values. These variations have been explained by considering the reabsorption of the spectral lines and the mathematical theory developed had explained quantitatively the observed experimental results.

To explain the rate of variation of intensity of the mercury triplet lines with arc current as has been observed in the present investigation, we assume

$$I_{ul} = (1 - A_S) I^0_{ul} \text{ (Sen and Sadhya}^9\text{)} \qquad \ldots (5)$$

where A_S is the self-absorption of the spectral line and I^0_{ul} is the intensity of the spectral line without self-absorption and

$$I^0_{ul} = n.\frac{g_u}{Z_0} A_{ul} h\nu_{ul} \exp\left[\frac{-(E_u - E_l)}{kT_e}\right]$$

and

$$A_S = f_{lu}\lambda_{ul}\rho . n_l(0) \qquad \ldots (6)$$

where f_{lu} is the absorption oscillator strength, λ_{ul} is the wavelength of the radiation,

$$\rho = \frac{1}{3}\pi r_0 C\left[\frac{M}{2\pi k T_g}\right]^{1/2} R \qquad \ldots (7)$$

and $n_l(0)$ is the population density at the axis of the discharge tube which is the same for all the three spectral lines. Eqs (5)-(7) have been deduced in the earlier paper[9]. If, as before, $I_{2.5}$ denotes the intensity of the spectral line at the initial current of 2.5 A, then

$$\frac{I_{ul}}{I_{2.5}} = \frac{(1 - A_S)_i}{(1 - A_S)_{2.5}}$$

$$= \left\{1 - f_{lu}\lambda_{ul}\frac{1}{3}\pi r_0 C\cdot\frac{M}{(2\pi K T_g)^{1/2}}\right\}\bar{C}$$

where $(1-A_S)_{2.5}$ can be regarded as constant and represented by $1/\bar{C}$; then

$$\frac{d}{di}\left(\frac{I_{ul}}{I_{2.5}}\right)=\frac{d}{di}[\bar{C}-\bar{C}\alpha T_g^{-1/2}]$$

where

$$\alpha=f_{lu}\lambda_{ul}\frac{1}{3}\pi r_0 C\frac{M}{(2\pi K)^{1/2}}$$

as no other term except T_g is a function of the arc-current (i), now

$$\frac{d}{di}[\bar{C}-\bar{C}\alpha T_g^{-1/2}]=\frac{\bar{C}\alpha}{T_g^{3/2}}\cdot\frac{dT_g}{di}$$

We thus observe that as dT_g/di will be the same for the three spectral lines investigated; the rate of variation of intensity with current will depend upon the value of α. From the expression used for α, it is further evident that for the three spectral lines all terms except f_{lu} and λ_{ul} are constants and hence $(d/di)(I_a/I_{2.5})$ will be proportional to $\lambda_{ul}f_{lu}$. Hence we can write

$$\frac{d}{di}\left(\frac{I_{ul}}{I_{2.5}}\right)_{4047Å}:\frac{d}{di}\left(\frac{I_{ul}}{I_{2.5}}\right)_{4358Å}:\frac{d}{di}\left(\frac{I_{ul}}{I_{2.5}}\right)_{5461Å}$$

$$\doteq(f_{lu}\lambda_{ul})_{4047Å}:(f_{lu}\lambda_{ul})_{4358Å}:(f_{lu}\lambda_{ul})_{5461Å}$$

The values of f_{lu} as provided by Gruzdev[12] are as follows:

$$(f_{lu})_{4047Å}=0.10,(f_{lu})_{4358Å}=0.114,(f_{lu})_{5461Å}=0.14$$

Hence

$$(f_{lu}\cdot\lambda_{ul})_{4047Å}:(f_{lu}\lambda_{ul})_{4358Å}:(f_{lu}\lambda_{ul})_{5461Å}$$

$$\equiv 0.2:0.24:0.38$$

whereas from our experimental data the ratio is 0.2 : 0.245 : 0.31. We thus observe that there is perfect agreement between theoretical and experimental results for the spectral lines λ4047Å and λ4358Å but there is some discrepancy with regard to the line λ5461Å.

With regard to increase of intensity with the application of magnetic field, the results are consistent with all previous observations[7,8] and the enhancement of intensity has been explained on the observation that the electron temperature increases and electron density decreases in a transverse magnetic field whereas the reverse process takes place when the field is longitudinal. Based on these postulates analytical expressions have been deduced which explain satisfactorily the observed experimental results. In the present investigation, however, a minimum in the intensity-magnetic field variation curve has been noted in the case of all the three spectral lines investigated.

We can now introduce the effect of self-absorption and see how the intensity of lines changes due to self-absorption in a transverse magnetic field; we have deduced in our previous paper[9] that

$$\frac{(I_{ul})_H}{I_{ul}}=1-f_{lu}\lambda_{ul}\rho\{n_l(0)_H-n_l(0)\}\left\{\frac{n_u(0)_H}{n_u(0)}\right\} \quad \ldots(8)$$

In Eq. (8), ρ is already defined by Eq. (7) and r_0 is the classical electron radius and C is the velocity of light and other symbols have their usual significance. When a transverse magnetic field is present, it has been deduced by Sen and Das[13] that if n_H and n_0 are the electron densities in presence and in absence respectively, of magnetic field, then

$$n_H=n_0\exp(-aH)$$

where $\quad a=\dfrac{eEC_1^{1/2}r}{2KT_eP}$

where E is the axial electric field, $C_1=\left[\dfrac{e}{m}\cdot\dfrac{L}{v_r}\right]^2$

where L is the mean freee path of the electron at a pressure of 1 Torr, v_r is the random velocity and r is the distance from the axis at which the electron density is n_H. Then we can write:

$$n_l(0)_H=n_l(0)\exp(-aH)$$

$$n_u(0)_H=n_u(0)\exp(-aH)$$

We assume that electron density in both the upper and lower levels are affected in the same way. Hence from Eq. (8) we get

$$\frac{(I_{ul})_H}{I_{ul}}=1-f_{lu}\lambda_{ul}\rho n_l(0)\{\exp(-aH)-1\}\exp(-aH)$$

$$=1-\alpha\exp(-2aH)+\alpha\exp(-aH) \quad \ldots(9)$$

where $\quad \alpha=f_{lu}\lambda_{ul}\rho n_l(0)$

Then we get from Eq. (9)

$$\frac{d}{dH}\frac{(I_{ul})_H}{I_{ul}}=2\alpha a\exp(-2aH)-\alpha\exp(-aH)$$

or $\quad H_{min}=\dfrac{\log_e 2}{a} \quad \ldots(10)$

From the experimental results it is evident that a minimum in the intensity magnetic field variation curve is observed in case of all the three spectral lines and the minimum occurs in the range 200-250 G.

The numerical value of a has been obtained from the measured data. The electric field per unit length in the mercury arc as measured is 1.6 V/cm, C_1 is the square of mobility of the electron in mercury vapour at a pressure of 1 Torr and has been taken as 2×10^{-6} by McDaniel[14]. The value of T_e has been taken to be 25000 K after Karelina[15] and confirmed by Sadhya[16] in this laboratory by a spectroscopic method. The inside pressure has been measured to be 0.05 Torr and a reasonable value of r has been taken as 0.333 cm. The computed value of a is found to be 3.496×10^{-3}. From Eq. (10) it is found that a minimum in the value of intensity-magnetic field variation curve can be expected to occur around 201.4 G. This is consistent with the experimental results obtained in the case of the three spectral lines, since in the intensity-magnetic field variation curve, a minimum is found to occur between 200 and 250 G. This shows that self-absorption plays a definite role with regard to intensity variation with arc current as well as with magnetic field.

Another noteworthy feature of the observed experimental results which is evident from Figs 2-4 is that in the case of all the spectral lines the increase of intensity in presence of magnetic field is greatest for the lowest arc current and the effect becomes less and less as the arc current is gradually increased. From Eq. (9) we get

$$\frac{(I_{ul})_H}{I_{ul}} = 1 - f_{lu}\lambda_{ul}\rho\, n_l(0)[\exp(-2aH) - \exp(-aH)]$$

It is thus evident that, for a particular spectral line, $f_{lu}\lambda_{ul}\rho$ and a are constants and the intensity becomes, for a certain value of H, a function of $n_l(0)$. From the above equation it is clear that as $n_l(0)$ decreases, that is as the current decreases, $(I_{ul})_H$ will increase which is consistent with experimental observation.

In the earlier paper[9] as well as in the present investigation the role of self-absorption in the emission spectrum of the mercury triplet series of lines has been brought out, specially its effect on the variation of intensities of the lines when the arc current and the external magnetic field are varied.

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