MAGNETIC FIELD EFFECT

ON THE POSITIVE COLUMN

OF FLUORESCENT LAMP

A Thesis

by

CHARLES JONG KIM

Submitted to the Graduate School of

Seoul National University

for the degree of

MASTER OF SCIENCE IN ENGINEERING

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ABSTRACT

The author studied the effects on the characteristics of 20-W fluorescent lamp when applying magnetic field to its positive column. First, when the direction of the magnetic field is longitudinal(along the lamp), if the magnitude of the field is stronger than the criti -cal field, lamp voltage is increased, lamp current decr -eased, luminous flux increased, starting voltage decrea -sed, as the applied field increases. At the magnetic flux density is 130 gauss, luminous flux is increased about 6 % and starting voltage is increased about 45 %.

Second, when the directoin of the magnetic field is transverse to the lamp axis, as the applied magnetic field increases, lamp voltage increased, lamp current decreased, luminous flux increased,and starting voltage is nearly constant. But the rates of increase or decreas -e of this case is larger than those of the first. At the magnetic flux density is 300 gauss, luminous flux is increased about 45 %.

In both cases, electric power dissipated by lamps is the same as that of the lamp which magnetic field is not applied to.

CONTENTS

I. INTRODUCTION

Fluorescent Lamp(FL) is the discharge lamp which, to pro-duce a radiation of rays, uses the region of positive col-umn in the glow discharge. The positive column is that part of the discharge between the cathode region and the anode region which is axially uniform. In most cases, the positive column will practically be what is called a plasm-a, that is, a gas with an equal and sufficiently large number of electrons and positive ions.[1,2,3,4]

There are two kinds of plasma; strongly ionized plasma and weakly ionized plasma. In the first kind of plasma, electron-electron collision is dominant but in that of the second, electron-ion(molecule) dominant. FL plasma is a member of the weakly ionized plasma.

The positive column has a negative resistance characteri-stics, which is different from the case in a metallic con-ductor, and therefore needs a stabilizing element in series.[5,6]

Below is the principle of radiating a light from FL;[7,8] the electrons which were escaped from hot cathode and accelerated by electric field smash the mercury molecules. Then the energy levels of mercury molecules are changed from ground states to excited states (to excite, electron needs a sufficiently large energy, i.e., high T_e in $mv^2/2$

$= 3kT_e$), and about 10^{-7}- 10^{-8} second after, changed from excited to ground. In the latter processes, the resonance line of 253.7 nm ultra-violet equivalent to the energy difference between excited and ground state ($dE = E_e - E_g = h\nu$) is radiated. The emitted ultra-violet radiations are converted into the radiations of longer wavelengths, i.e., visible radiations during they are absorbed in the phosphored inner wall (Stoke's law).[9]

At nowadays, the efficacy of FL is about 45 lm/W , and there are having been continuous studies to improve the properties. For example, the relations of lamp current and electron temperature(T_e) and lamp voltage were studi -ed,[8,11-18] and the relation of wall temperature and pre -ssure was studied, too.[13-16]

In practice, there are a few tries to increase the effic -acy, by reducing the lamp current (helicoidal structure,[10] recombination structure - glass wool[11,19]), and by the equipment to lower the wall temperature (thermal - radiating plate behind the electrode[13]).

The purpose of this paper is to study the variations in the voltage, current, luminous flux, spectrum distribution , and starting voltage of FL, when applying a longitudinal and a transverse magnetic field to it, respectively.

II. THEORETICAL CONSIDERATIONS

When there is a interaction between particles, to find the average velocity $\underline{u}$ at any point in space for the electrons in this plasma where there are electromagnetic forces acting, we use the Langevin equation.[20-25]

$$m\dot{\underline{u}} = -e(\underline{E} + \underline{u} \times \underline{B}) - m\phi\underline{u} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where m is the electron mass

e is the magnitude of the electron's charge

ϕ is called the electron collision frequency and is the number of collisions per second which the average electron has with the heavy particles in the plasma

$\underline{E}$ and $\underline{B}$ are the electric and magnetic fields which act upon the electrons and may be either externally applied or self-induced by currents in the plasma.

Equation(1) provides an equation for the average electron velocity $\underline{u}$. Natually, this flow of electrons corresponds to a current density.

$$\underline{J} = -ne\underline{u} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

so that the Maxwell curl equations become

$$\text{curl } \underline{E} = -\dot{\underline{B}} \qquad \text{curl } \underline{H} = \dot{\underline{D}} - ne\underline{u} \ .$$

Now, for traveling plane waves, $\underline{E}$, $\underline{B}$, and $\underline{u}$ are all proportional to $\exp(i\underline{k}\cdot\underline{r} - i\omega t)$. Hence, the operation d/dt becomes,

$$d/dt = -iw \quad \text{.......(linearization[24])} \quad ....(3)$$

Applying this operator to Eq.(1), we have

$$-imw\underline{u} = -e(\underline{E} + \underline{u} \ \underline{x} \ \underline{B}) - m\phi\underline{u}$$

i.e.,

$$0 = -e(\underline{E} + \underline{u} \ \underline{x} \ \underline{B})/m - (\phi - iw)\underline{u} \quad ....(4)$$

Hence, from Eq.(2), we obtain

$$\underline{J} = ne^2(\underline{E} + \underline{u} \ \underline{x} \ \underline{B})/(m (\phi - iw)) \quad ....(5)$$

and Eq.(5) can be,

$$\underline{J} = s\underline{E} + s\underline{u} \ \underline{x} \ \underline{B} \quad ....(6)$$

where $s = ne^2/m(\phi - iw)$; conductivity

And in addition we raplace $\underline{u}$ by $-\underline{J}/en$, to have

$$\underline{J} = s\underline{E} - (s\underline{J}/ne) \ \underline{x} \ \underline{B} \quad ....(7)$$

Thus

$$\underline{J} = s\underline{E} - (e/(m (\phi - iw)))\underline{J} \ \underline{x} \ \underline{B} \quad ....(8)$$

On the other hand, lamp voltage V_l in the discharge lamp is known as Eq.(9).

$$V_l = (64/3.14)^{1/4}(X(T_e))^{1/2}(kT_e/Z\_e) \text{ V/cm} \quad ....(9)$$

i.e., V_l is proportional to T_e .

And, the population of 6 ^3p (i.e., 253.7 nm resonance radiation) @ is,[8]

$$@ = n_a(g/g_a) \exp(-eV_e/kT_e) \quad ....(10)$$

and in other notation (and we define an operator $\ast\!\!\!\ast$ as an operator of direct proportion),

$@ ⁑ \exp(-K/T_e)$,   K : constant ....(11)

Hence, from Eq.(9), approximately we can obtain

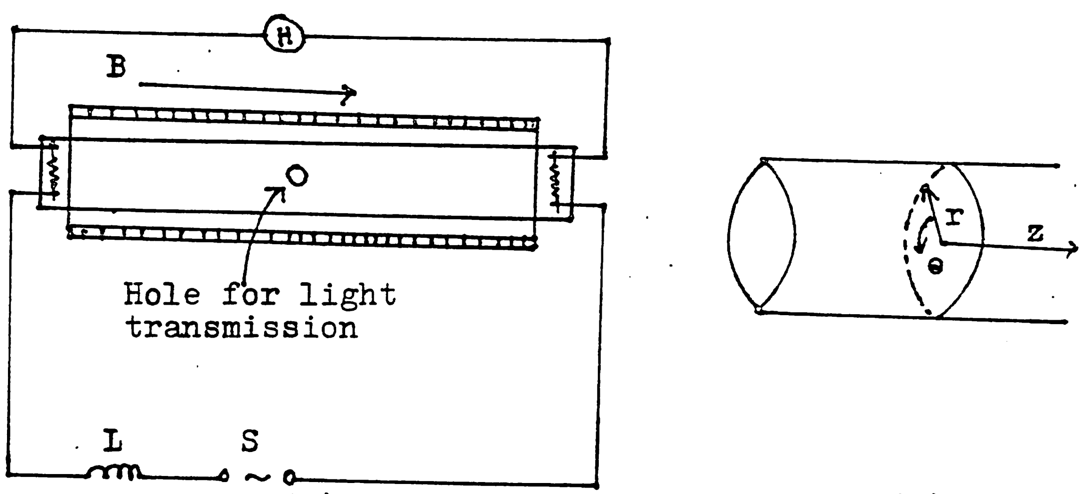
$@ ⁑ \exp(-K'/V_1)$. K' : constant ....(12)

In addition, starting voltage V_b (or breakdown voltage) of discharge lamp is,[4)]

$V_b ⁑ (w/\phi)$ where w ; frequency

II.A The Case Of Applying Longitudinal Magnetic Field

We can choose our device(a) and coordinate(b) as Fig.1.



(a) (b)

Fig.1 Longitudinal magnetic applying device and its coordinate system.

Then we can obtain $\underline{J}$ according to the coordinate.

From Eq.(8), we obtain

$$\underline{J} = s\underline{E} + (W_c/(\phi - iw))\underline{J} \; \underline{x} \; \underline{a}_z \quad ....(8)'$$

where W_c ; $-Be/m$, cyclotron frequency

$\underline{a}_z$; z-directional unit vector

In cylindrical coordinate, $\underline{J}$, $\underline{E}$ and $\underline{B}$ can be written as below

$$\underline{J} = J_r\underline{a}_r + rJ_\theta\underline{a}_\theta + J_z\underline{a}_z$$

$$\underline{E} = (E_r\underline{a}_r + rE_\theta\underline{a}_\theta + E_z\underline{a}_z) \exp(-iwt) \qquad (13)$$

$$\underline{B} = (B_r\underline{a}_r + rB_\theta\underline{a}_\theta + B_z\underline{a}_z) \exp(-iwt)$$

After, $\exp(-iwt)$ will be omitted for convenience. We write Eq.(8)' by components using Eq.(13). In this case, $E_\theta= 0$, $B_r= B_\theta= 0$, and E_r is a radial potential.[2,3,4]

Thus the equations are,

$$J_r = sE_r + (W_c/(\phi - iw))rJ_\theta \quad ....(14)$$

$$J_\theta = (1/r) (W_c/(\phi - iw)) (-J_r) \quad ......(15)$$

$$J_z = sE_z \quad ....(16)$$

When the magnetic field B is zero ($W_c= 0$), Eqs.(14), (15), (16) can be rewritten as,

$$J_r = sE_r \quad ....(14)'$$

$$J_\theta = 0 \quad ....(15)'$$

$$J_z = sE_z \quad ....(16)'$$

We have absolute magnitudes of Eq.(14) and (15).

$$J_r = (s/(1 + (W_c + \phi)^2))E_r \quad \text{..........(17)}$$

$$J_\theta = (s/(1 + (W_c/\phi)^2)) (-W_c/r\phi)E_r \quad \text{..(18)}$$

If we use new parameters as

$$s_r = (s/(1 + (W_c/\phi)^2))$$

$$s_\theta = s(W_c/\phi)/(1 + (W_c/\phi)^2).$$

Fig.2 shows the graphs of s_r and s_θ as a function of (W_c/ϕ). In Fig.2, because ϕ is usually very great (about order of $10^8 - 10^9$), (W_c/ϕ) is smaller than 1. Thus we consider only the finite regi -on that s_r is decreasing and s_θ is increasing, resp -ectively.

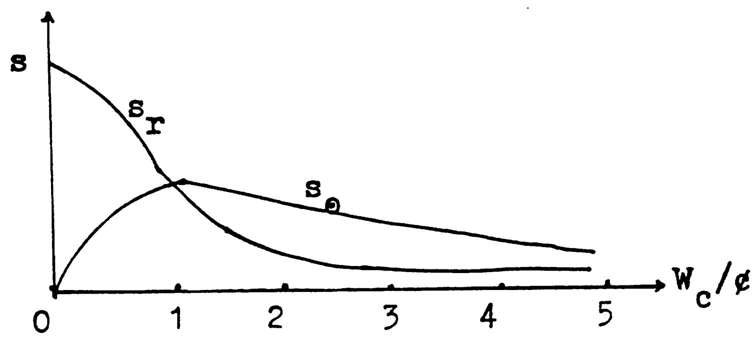


Fig.2 Graphs of s_r and s_θ as a function of W_c/ϕ .

From the above considerations, J_r decreases and J_θ increases as B is increasing. As magnetic field incre -ases, electrons are not spread out to the wall but concentrate on the center and have a helical motion.

Therefore ϕ in substantial increases. Athough lamp current, J_z, is same in Eqs.(16) and (16)', it is affe-cted by J_r and J_θ (in terms of ϕ) and begins to decrease (from critical field B_c).[23, 28-31]

From Eq.(8), we have

$$J_z = (ne^2/m(\phi - iw))E_z \exp(-iwt).$$

The real part of the above equation is,

$$J_z = (ne^2/m(\phi^2 + w^2)^{\frac{1}{2}}) \sin(wt - q)E_z . (19)$$

where, $q = \arctan(w/\phi)$

From Eq.(19) and Lissajours Patterns of J_z and E_z, we can obtain the information of ϕ. But, if w is not very high frequency (microwave), (w/ϕ) is nearly zero, we can not measure precisely and even roughly.

And the starting voltage will decrease because of the increased ϕ.

II.B The Case Of Applying Transverse Magnetic Field

We choose our device(a) and coordinate(b) as Fig.3. Then we can obtain $\underline{J}$ according to the coordinate.

From Eq.(8), we can obtain the components of current density.

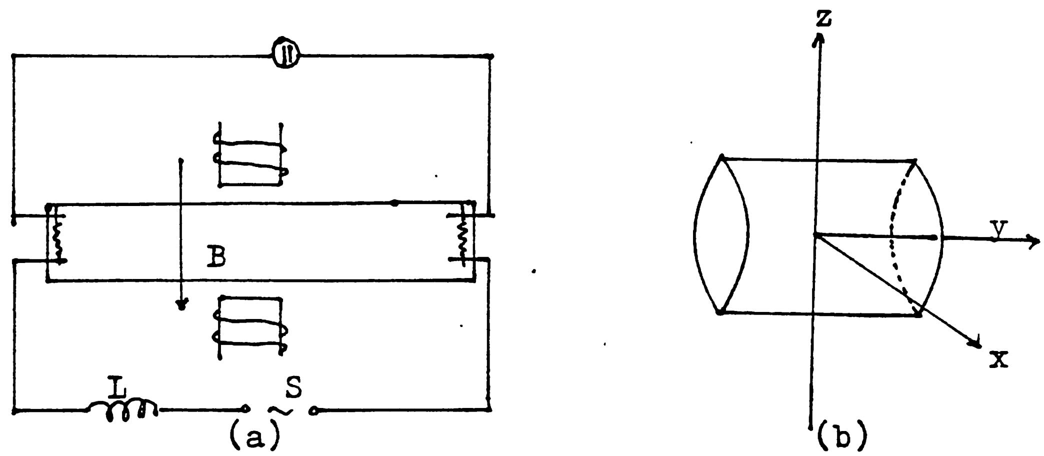


Fig.3 Transverse magnetic field applying device and its coordinate system .

$$J_x = sE_x + (\ W_c/(\ \phi - iw\ ))J_y \quad \ldots\ldots\ldots\ldots(20)$$

$$J_y = sE_y - (\ W_c/(\ \phi - iw\ ))J_x \quad \ldots\ldots\ldots\ldots(21)$$

$$J_z = sE_z \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(22)$$

Eqs.(20), (21), (22) can be rewritten as

$$J_x = (\ sE_x/(\ 1 + W_c/(\ \phi - iw\ ))$$
$$+ s(\ W_c/(\ \phi - iw\ ))E_y/(\ 1 + (\ W_c/(\ \phi - iw))^2) \quad \ldots\ldots\ldots\ldots(20)'$$

$$J_y = -s(\ W_c/(\phi - iw))E_x/(\ 1 + (\ W_c/(\phi - iw))^2)$$
$$+ sE_y/(\ 1 + (\ (\ W_c/\phi\ ) - iw\ )^2) \quad \ldots\ldots(21)'$$

$$J_z = sE_z \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(22)$$

where, E_x' , E_z = radial potential

When B is zero,

$$J_x = sE_x \qquad (24)$$

$$J_y = sE_y \qquad (25)$$

$$J_z = sE_z \qquad (26)$$

Thus, we obtain the relation such as;

$J_y(B \neq 0)$ is smaller than $J_y(B = 0)$

$J_x(B \neq 0)$ is larger than $J_x(B = 0)$.

On the other hand, from above considerations, as ϕ is decreased, starting voltage must be considered as a mobility-dominated case.

III. EXPERIMENTAL RESULTS AND ANALYSES

III.A The Case Of Applying Longitudinal Magnetic Field

In Fig.1, as magnetic flux density is changed, lamp voltage and lamp current and luminous flux and spectrum intensity and starting voltage are measured.

(a) lamp voltage and lamp current (Fig.4)

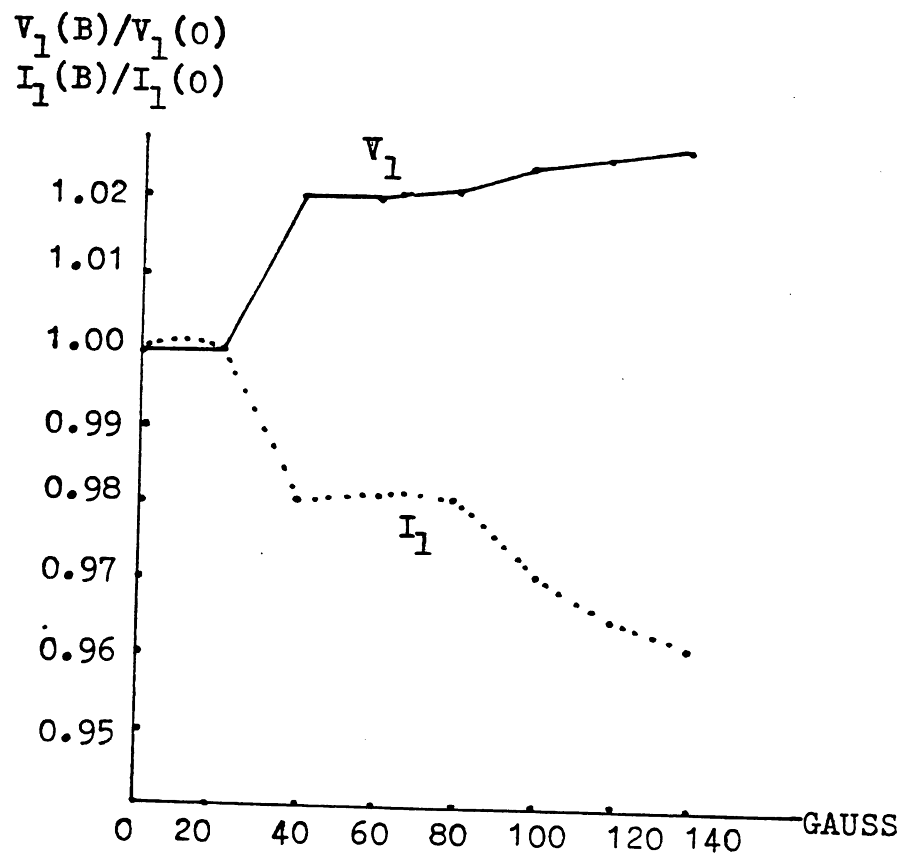


Fig.4 Voltage and current graph when applyin -g longitudinal magnetic field.

Although $J_z(0) = J_z(B)$ only from Eqs.(16) and (16)' , because J_z is a function of ϕ , as J_r decreas -es and J_θ increases as B increases, and ϕ is increa -sed, J_z decreases as B increases.

In the classical collision-diffusion theory, current increases as B increases. But, as mentioned at 'Theor -etical Considerations', current decreases when B is larger than some critical field B_c. In experiment, when B = 0 - 20 gauss, it corresponds to the classical theory (classical region) and when B is larger than 20 , current decreases (experimental region*).

(b) spectrum line intensity (Fig.5)

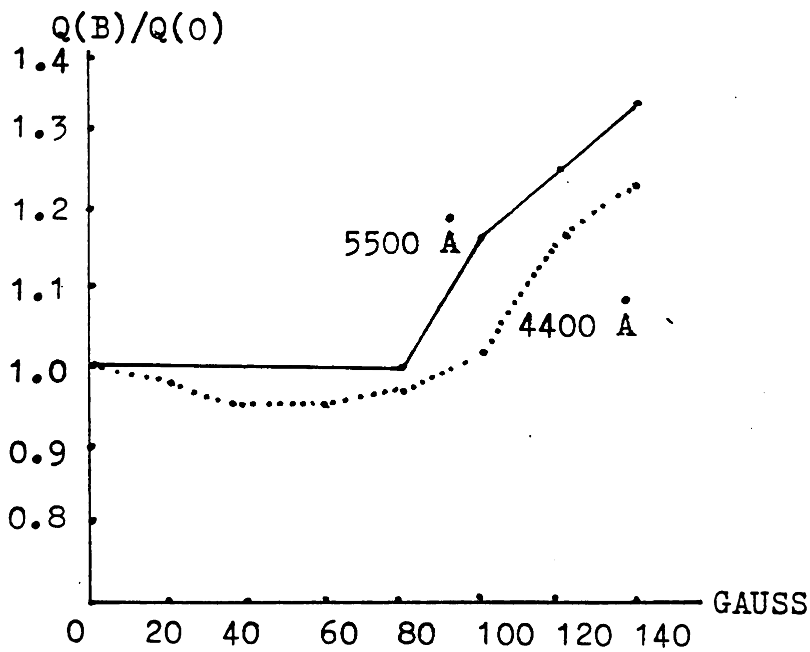


Fig.5 Spectrum line intensity graph when applying longitudinal magnetic field.

Variation of spectrum line is less sensitive than that of current and voltage. 4400 Å , 5500 Å lines are constant till B = 80 gauss. After 80 gauss, lines incr

-ease steeply. This phenomenon is such that; when magnetic field increases, so does lamp voltage, and spec-trum intensity also increases by Eq.(12).

(c) spectrum distribution and intensity (Fig.6)

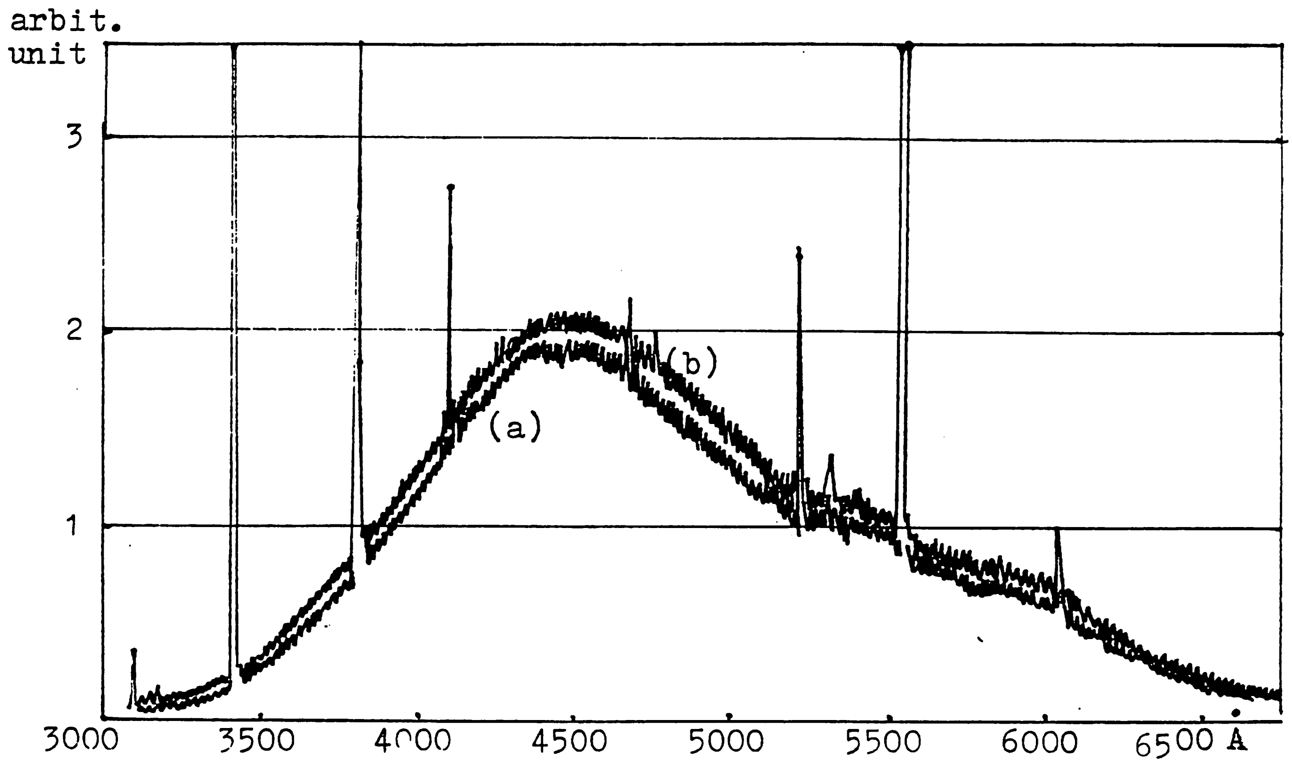


Fig.6 Spectrum distribution graph when applying longitu-dinal magnetic field (a)zero and (b) 130 gauss

Fig.6(a) and 6(b) are the spectrum distributions when magnetic flux density is zero and 130 gauss, respective-ly. In the whole, there is a about 10 % increase in in-tensity. There is no shift of distribution.

It is self-explanatory to be shown like above graphs by Eq.(12) and Fig.5 .

(d) luminous flux (Fig.7)

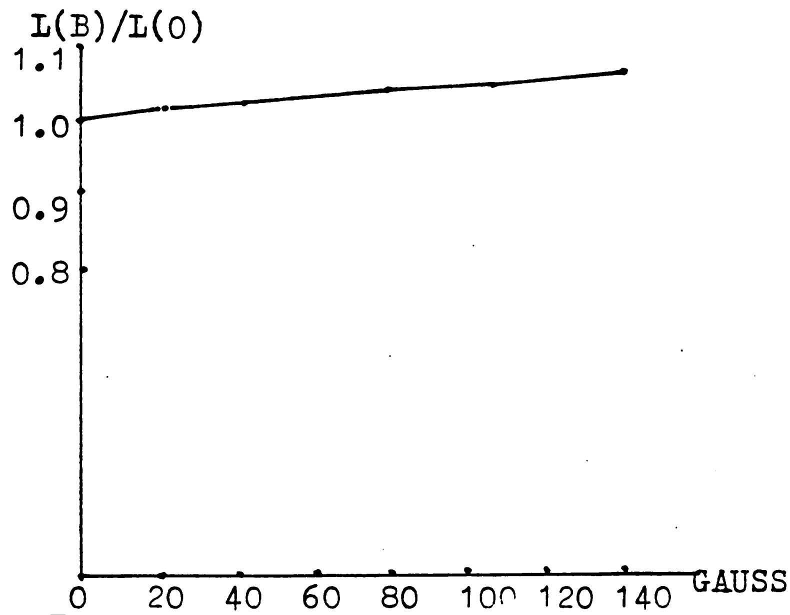


Fig.7 Luminous flux graph when applying longitu -dinal magnetic field

As the spectrum distribution is increased, so will be the luminance. We can explain this effect clearly by Eq.(12) and increased voltage.

Approximately, empirical equation of smooth curve make -s

$$L(B) = (0.00044\, B + 1)\, L(0) .$$

where L(B); luminous flux when $B \neq 0$

L(O); luminous flux when $B = 0$

B ; magnetic flux density in the unit of gauss

When B = 100 gauss, there is about 4 % increase.

(e) starting voltage (Fig.8)

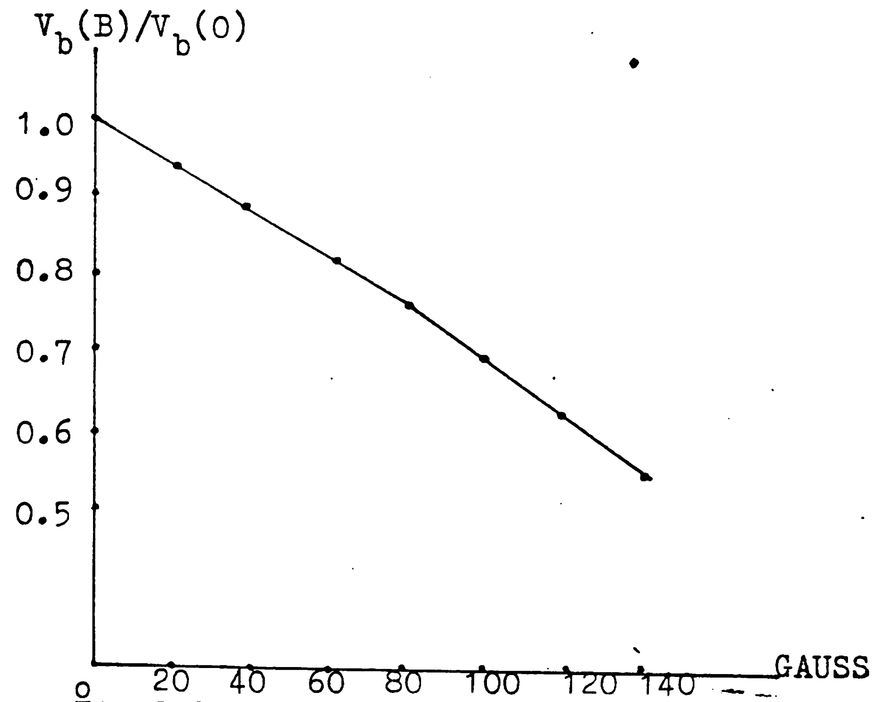


Fig.8 Starting voltage graph when applying longitudinal magnetic field

When B = 0 - 80 , starting voltage is decreased linea-rly, and when B is larger, the slope is steeper.

Approximately, the empirical equation of smooth curve makes

$$V_b(B) = (1 - 0.00322 B)V_b(0) .$$

where $V_b(B)$; starting voltage when $B \neq 0$

$V_b(0)$; starting voltage when $B = 0$.

When $B = 100$ gauss, there is about 32 % decrease in starting voltage. By Eq.(13), as starting voltage is pro-portional to $1/\phi$, and ϕ is increased , V_b decreases.

III.B The Case Of Applying Transverse Magnetic Field

(a) lamp voltage and lamp current (Fig.9)

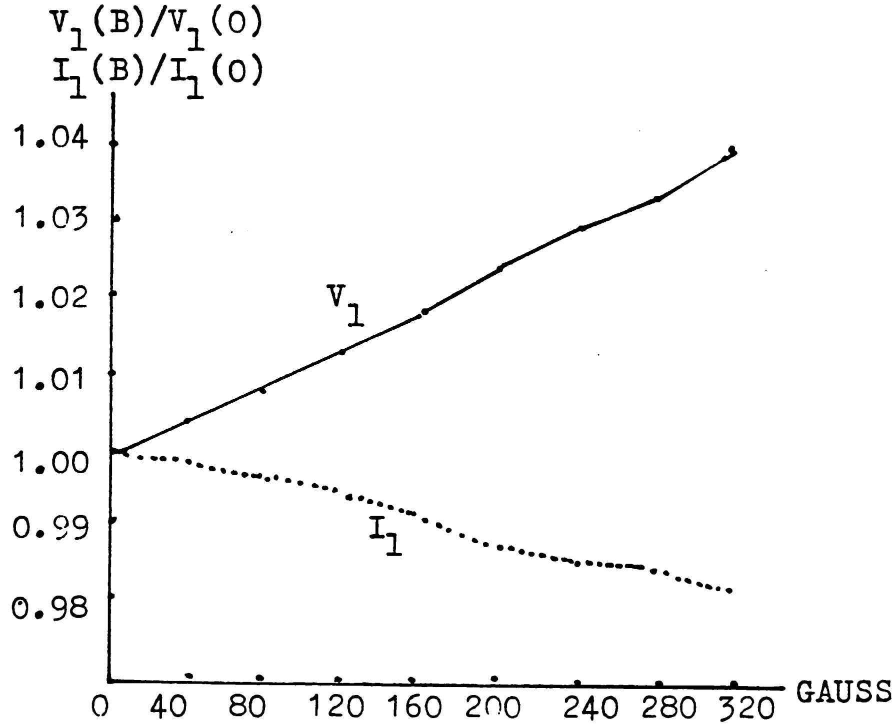


Fig.9 Voltage and current graph when apply-ing transverse magnetic field.

Variation of voltage and current is well corresponds to the theory (cf. Eq.(21)'). Current decreases and voltage increases as B increases. Because $J_y(B \neq 0)$

is smaller than J_y(B = 0) and J_x(B ≠ 0) is larger than J_x(B = 0), electrons are spreaded to the wall and J_y, the lamp current, is decreased. Voltage is incr-eased by the negative resistance characteristics.

(b) spectrum line intensity (Fig.10)

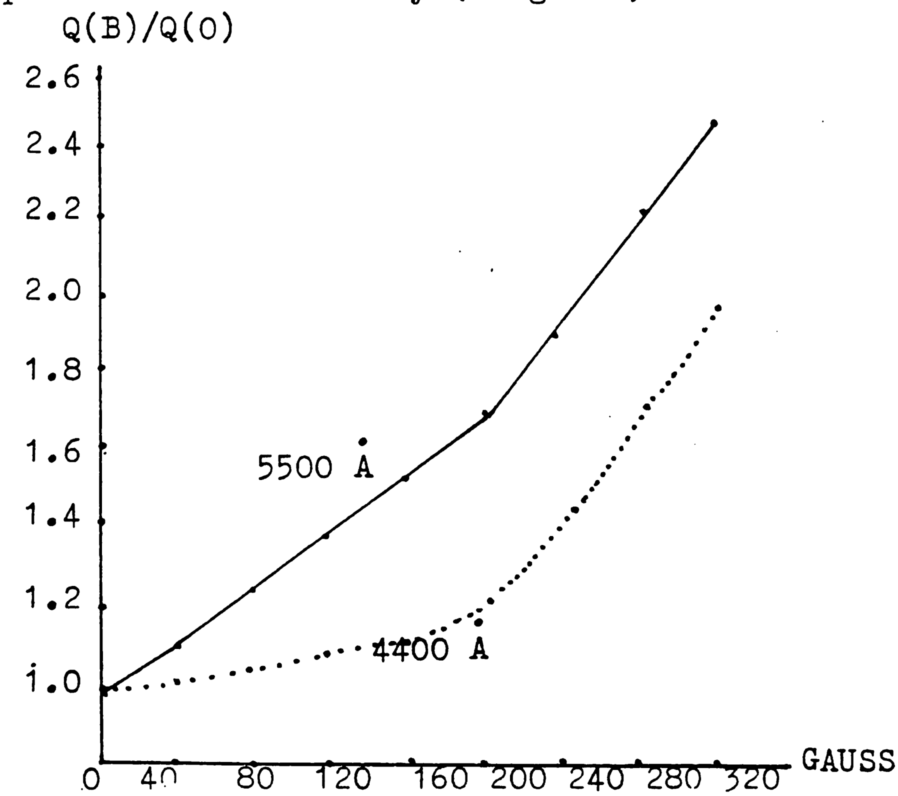


Fig.10 Spectrum line intensity graph when apply-ing transverse magnetic field.

4400 Å , 5500 Å lines are increasing as magnetic field flux is increasing. We can explain this effect by Fig.9 and Eq.(12) .

(c) spectrum distribution and intensity (Fig.11)

Fig.11(a) and 11(b) are the spectrum distributions when the applying magnetic flux density is zero and 300 gauss, respectively.

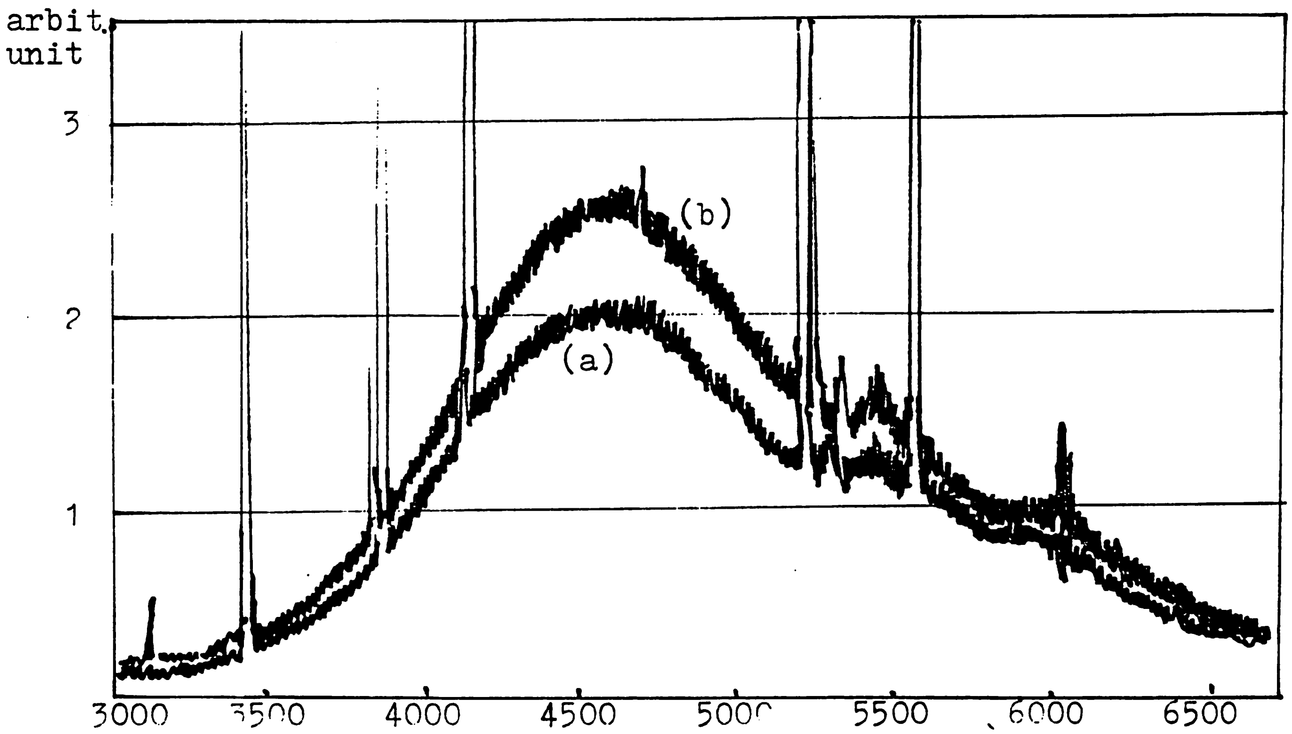


Fig.11 Spectrum distribution graph when applying transverse magnetic field (a) zero and (b) 300 gauss.

Increased voltage makes the line intensity increase and makes the spectrum distribution increase. In a whole there is about 30 % increase.

(d) luminous flux (Fig.12)

Luminous flux increases according as spectrum intensit-y increases. But the slope of increase is steeper than that of the case of the applying longitudinal magnetic field.

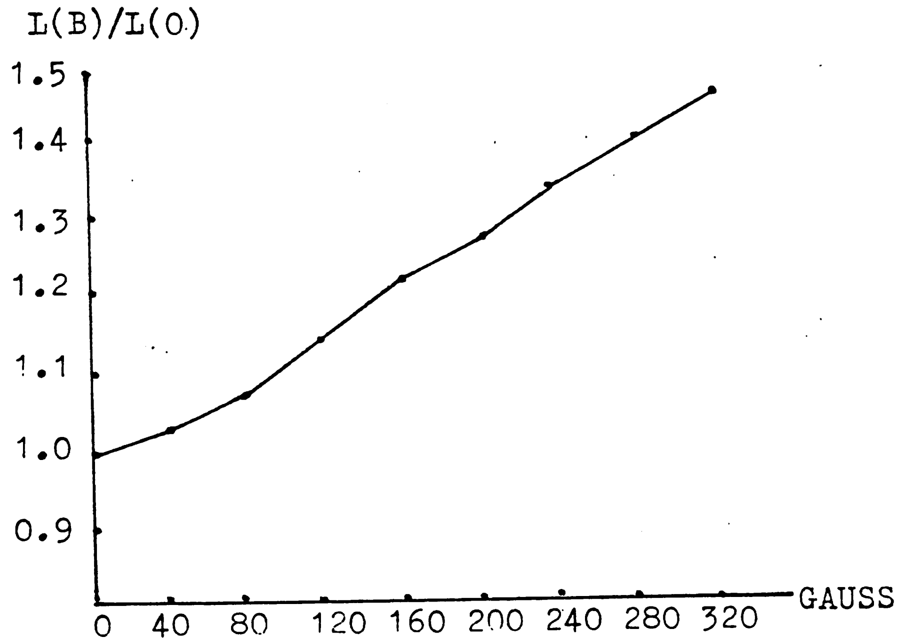


Fig.12 Luminous flux graph when applying transverse magnetic field.

Empirical equation of smooth curve approximation makes,

$$L(B) = (0.0015 B + 1)L(0).$$

When B is 300 gauss, there is about 45 % increase in luminance.

(e) starting voltage (Fig.13)

As we see in Fig.13 , starting voltage is maximum at B = 20 gauss and decreases slowly to the value of the case B = 0 as B is increasing.

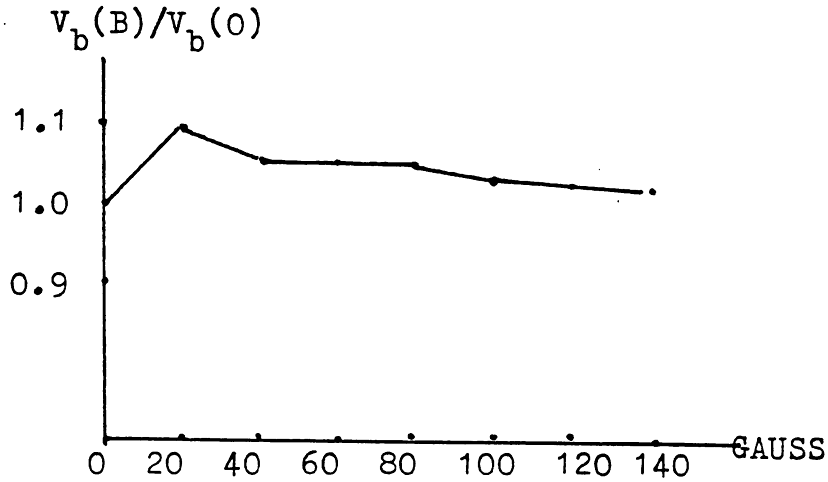


Fig.13 Starting voltage graph when applying transverse magnetic field.

In this case of the starting voltage, we consider in mind the sheaths in the wall and ambipolar diffusion which is different from the case of the longitudinal magnetic field. The affecting factors, the author thinks, are the diffusion-controlled mechanism and the sheaths which repel the electrons, ambipolar diffusion.

IV. CONCLUSIONS

If we apply longitudinal magnetic field, lamp voltage increases and lamp current decreases (if B is larger than B_c), and by Eq.(12) luminous flux increases. And the starting voltage decreases by the increased coll -ision frequency.

If we apply transverse magnetic field, lamp voltage incr -eases and lamp current decreases and luminous flux incr -eases. But the slope of increase or decrease is not the same in two cases of applying magnetic field. The latter case (i.e., transverse field) is steeper. The starting voltage is nearly the same as that of the zero-field.

In each case above, the power dissipated has no change and the life time of the lamp has no change, either.

In a brief, we can say that;

1. If we apply the longitudinal magnetic field, we can decrease the starting voltage greatly, but there is nearly no benefit in the view of the efficacy.
2. If we apply the transverse magnetic field, we can get great a benefit in the view of the efficacy,but there is nearly no change in the starting voltage.

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