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RESEARCH REPORT

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THE STUDY OF THE PRE-IONIZATION OF THE FAST TOROIDAL PINCH

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Abstract

Techniques and the mechanisms of the pre-ionization of the fast toroidal pinch system have been studied. Among the various tested techniques, electron beam injection into the discharge tube is most satisfactory. A special electron gun capable of extracting 1 A has been developed. Using this gun, the break-down is possible down to 2 mtorr in D_2 gas. In addition to the Townsend's α process, it is found that the electron drift due to the toroidal effect and the turbulent diffusion by the drift dissipative ion=acoustic instability seem to play an important role on the build up of the discharge in a high E/p fast toroidal pinch experiment.

§1. Introduction

It is well known that magnetic β value of the ordinary θ-pinch plasma is too high to contain it by an axial-symmetric toroidal pinch system, due to the lack of equilibrium and stability. The maximum permissible β value of the TOKAMAK configuration is estimated to be $\sim a/Rq^2$ (Mukhovatov and Shafranov., 1971), which, at most, is from 0.1 to 0.2. Here, a is the diameter of the plasma, R is the major radius of the torus and q is so called safety factor. Even for ZETA type configuration with reversed toroidal field outside the plasma (Robinson., 1971), β less than 0.4 seems to be preferable. The efforts to reduce the β value without also lowering the plasma temperature become important. One of the solutions for this problem is achieved by reducing the initial gas pressure much less than in ordinary θ-pinches or screw pinches. This idea is based on the fact that the anomalous field diffusion during implosion phase occures below some critical line density, say, 10^{16}/cm (McCartan., 1969).

On the above standpoint, reproducible low pressure operations become important for the toroidal pinch experiment. Therefore, developing of reliable and convenient techniques for pre-ionization of low pressure gas is significant. For this reason, there appeared several papers concerning this subject (Sand and Waidman., 1970, Malesani et al., 1970, Eberhagen, 1970). However, the pre-ionization techniques studied previously were mainly concentrated on r.f. discharges. Here, in addition to the widely used r.f. discharge, electron beam injection into the torus is studied intensively. The effect on the break-down time of the electrostatic potential of the copper shell which surrounds the glass torus is also studied.

Based on this fundamental study, a powerful electron gun capable of extracting a 1 A electron beam is made to realize simpler and more accurate pre-ionization techniques.

Discussions on the mechanism of the break-down of the low pressure gas with high E/p value in the toroidal discharge system is given. We have reached some different conclusions to the previous contributions (Malesani et al, 1970. Rose and Clark, 1961). The electron temperature and density measurements of the pre-heating phase is also presented.

§2. Experimental Apparatus

The schematic drawing of the apparatus is shown in Fig. 1. The glass torus is covered by four pieces of copper shell of 1 mm thickness. The major and minor diameters of the glassware are 24 and 6 cm, respectively. In order to induce the toroidal electric field E around the torus, two one-turn induction coils of copper belt are wound just outside the inner and outer periphery of the copper shells. They are connected in parallel. The coils for the toroidal stabilizing magnetic field B are wound directly on the shells and on the induction coils so as to simplify the construction of the system. Rough arrangement of the coils is permitted, since the copper shell cancels the error field automatically. The maximum strength of B attainable is 15 kG. It rises to the maximum within 25 μsec. The capacitor for the toroidal electric field is 12 μF and can be charged to 15 kV, in which case electric field strength E along the minor axis of the torus becomes 260 V/cm. The ringing frequency of the current through the induction circuit is 100 KHz.

For the study of pre-ionization, the r.f. oscillator similar to Eberhagen's (Eberhagen 1970) is made. The typical wave form of the oscillation is shown in Fig. 2. The r.f. frequency of this oscillator was 5MHz and the maximum out put voltage was 7.5 kV. In order to minimize the spacing between the plasma and the copper shells, r.f. electric field is applied directly between the insulated neighboring shells. We did not use the special electrodes of Eberhagen (1970) or Sand and Waidmann (1970) (Fig. 1).

At first, the usual electron gun having Wenelt's electrode was used and was attached to the horizontal port of 18 mm diameter. The electron beam was injected perpendicular to the minor axis of the torus. By using this gun, an electron beam up to 2 mA can be obtained continuously when the extracting voltage is set to 7.5 kV. In the course of study, electron beam injection was found to be very effective tool for pre-ionization, so that a simple and powerful electron gun capable of extracting 1 A electron beam has been made and tested. The schematic drawing of this gun is given in Fig. 3 together with its operation circuit. The typical example of the current wave form of the electron beam is shown in Fig. 4. The electron stream is accelerated into the discharge tube by the grid just in front of the spiral hot filament. In order to pull back the stray electrons produced by the electron gun or natural radioactivity away from the pumping port, the electrostatic potential is applied to the shells. Of course, the vacuum pump is grounded, so the high tension is applied between the shells and the vacuum pump.

The plasma current was measured by a Rogowski coil wound around the glass torus. The density and the electron temperature of the pre-heated plasma are measured by usual floating double probes.

§3. Experimental Results

Wave forms of the plasma current and the one-turn voltage to drive it are given in Fig. 5. As can be seen, there appears a sudden rise on the current trace and drop on the voltage trace at the time when the break-down occurs. If the discharge current grows exponentially following Townsend's α process, the relation between the current and the voltage should be resistive at the very early stage of the discharge. However, it turns into an inductive relation as the discharge proceeds and the current is limited by the self-inductance. This is the reason why the observed current rises linearly at the beginning. Therefore, we can conveniently define the break-down time Δt_B as the time when the plasma current become inductive. As shown in Fig. 6, this Δt_B is easily obtained from the current trace by reading the cross point of the tangential line of the current curve to the abscissa.

The above process is written as follows;

$$i = i_0 \exp \frac{t}{\tau_B} , \tag{1}$$

where i is the discharge current, i_0 is the current when $t = 0$ and τ_B is the time constant of the current growth. Using the drift velocity u of the electron, initial electron density n_0 and cross-section S of the discharge,

$$i_0 = en_0uS . \tag{2}$$

By the definition of Δt_B, the relation,

$$V_0 = L_p\left(\frac{di}{dt}\right)_{t=\Delta t_B} = \frac{L_p}{\tau_B} i_0 \exp \frac{\Delta t_B}{\tau_B} , \qquad (3)$$

holds, where V_0 is the one-turn voltage and L_p is the inductance of the plasma. If we use the simple relation,

$$u = \frac{e\tau_{en}}{m_e} E = \frac{e\tau_{en}}{m_e} \frac{V_0}{2\pi R} ,$$

in addition to eq (2), eq. (3) can be reduced to the form,

$$\frac{\Delta t_B}{\tau_B} = \ln\left[\left(\frac{\tau_B}{\tau_{en}}\right) \frac{2\pi R m_e}{L_p e^2} \frac{1}{N_0}\right] . \qquad (4)$$

Here, τ_{en} is the electron neutral collision time, R is the major radius of the torus and N_0 is the initial line density of the electrons. It is easily seen that $\Delta t_B/\tau_B$ becomes a slowly varying function of only N_0 and independent of the parameter of the torus, because both τ_{en} and τ_B are inversely proportional to initial pressure approximately, and L_p is propotional to R. Therefore, if N_0 is nearly constant throughout the experiment, the measured Δt_B is proportional to τ_B which becomes important quantity when the mechanism of the breakdown is discussed.

In the first place, Δt_B is measured without using any pre-ionization techniques, as a function of the filling pressure p and the magnetic inductions B. Results are shown in Fig. 7. It is seen that application of B greatly reduces Δt_B.

As stated in the previous section, three different techniques (r.f. breakdown, potential on the shells, and the electron beam) for the pre-ionization are prepared and tested. Typical example of the results using these techniques are given in Table 1. Note that the old, low-current electron gun was used here. The combined use of the techniques seems to have a powerful effect. For instance, if these three techniques are used together, Δt_B is reduced more than factor 3 compared to the case with no pre-ionization. Because Δt_B is logarithmically proportional to N_0, the initial electron line density, this means that N_0 becomes more dense by more than 1 order of magnitude when the combined pre-ionization techniques are all used together.

The detailed study of each techniques has also been done. The delay time between the start of r.f. oscillation and the application of inductive E field has a significant influence on Δt_B. Fig. 8 shows some of the data obtained in the case when the application of E is synchronized at the maximum of B. The optimum operation in this case is to switch-on the r.f. oscillator 1 to 6 μsec before E is applied. It is noted that, when the r.f. is triggered before the start of B, Δt_B becomes longer than that in the case with no r.f.

The experimental results of changing the electron beam current and the shell potential are shown in Table 2, and 3. As can be seen, both a larger electron beam and a positive shell potential give a good effect on the break= down.

The interesing characteristic appears when Δt_B is measured as a function of B. As presented in Fig. 9, Δt_B becomes minimum around 1000 G. The same tendency is also observed by Eberhagen (1970) and Malesani et al (1970). Although the value of B for minimum Δt_B remains roughly constant around 1000 G with the change of E/p, the minimum Δt_B itself is an increasing function of E/p. The plotted curve of Δt_B vs E/p on Fig. 10 is the one when B_t is 1000 G. From these results, it is suggested that the secondary electron emission from the surface of the glassware by ion or electron bombardment is not important for the break=down, since the γ value, the secondary electron emission coefficient, is an increasing function of E/p. It is noted that Δt_B for H_2 is larger than that for D_2. The detailed discussion on the break-down mechanism will be given in the next section.

The newly developed electron gun has also been tested under maximum electron current of 1 A. This new gun makes Δt_B as short as in the case when the previous three techniques are used together. Indeed, if this powerful electron gun is used, the application of r.f. field and the shell potential do not have any significant effect on Δt_B. The optimum operating condition under 1 A beam is obtained when the beam is triggered from 200 to 800 μsec before the start of B_t field.

The plasma density and electron temperature after the break-down of the gas have been measured by a double probe.

The example of the wave form of the ion saturation current is seen in Fig. 11 when the maximum plasma current is fixed at 7 kA and B_t at 960 G. The deuterium plasma density just after the decay of the current changes with the filling pressure as shown in Fig. 12. The typical electron temperature in these cases is about 2 eV. The maximum ionization of 85 % is attained when the filling pressure is 16 mtorr.

§4. Discussions

As stated in the previous section, the break-down characteristic with respect to B is remarkably interesting; the Δt_B decreases monotonically as B increases toward 1000 G, but it reverses to increase slowly in the range of higher field. Efforts to explain this characteristic have been made. In the following discussion the time constant τ_B of current or ionization growth is used instead of Δt_B for convenience. It is already demonstrated that τ_B is proportional to Δt_B.

As is known, the τ_B is expressed by the formula

$$\frac{1}{\tau_B} = \frac{1}{\tau_i} - \frac{1}{\tau_c} \qquad (5)$$

where τ_i is the inverse of ionization rate and τ_c is the electron confimenent time in the torus. The relation between τ_i and the Townsend's first ionization coefficient α is

$$\frac{1}{\tau_i} \cong \alpha v_e \qquad (6)$$

provided v_e is the average velocity of the electrons. If the electrons are lost by the diffusion process,

$$\frac{1}{\tau_c} = \frac{D_e}{\Lambda^2} \; . \qquad (7)$$

Here, D_e is the diffusion coefficient of electrons and Λ is the so called diffusion length.

In the case that τ_c is much larger than τ_i, only Townsend's α process contributes to the break-down phenomenon. However, it becomes obvious, from the following two points, that the loss or diffusion of electrons during break=down phase plays an important role on the break-down process even in the case of strong magnetic field.

(1) The break-down time Δt_B of D_2 is shorter than that of H_2, as shown in Fig. 10. Without taking the loss process into account such a fact is difficult to explain, since D_2 and H_2 has the same value of α as long as E/p is not very small (Rose, 1956). In this experiment the value of E/p ranges from 10^2 to 10^4 V/cm torr.

(2) Gerjouy and Stuart (1960) predicted that α and $1/\tau_i$ become maximum when E/p is around 2,000. If it is so, and if the loss is neglected, the minimum should

appear on the curve of Δt_B vs E/p where E/p is about 2,000. It is shown, however, in Fig. 10 that the observed Δt_B is only an increasing function of E/p as long as E/p is larger than 400 V/cm torr. Therefore, if the prediction of Gerjouy and Stuart (1960) is true, the loss of the electrons must introduce a significant effect on the break-down process.

To clarify what kind of loss process is important, various loss velocities are estimated under the condition that E/p is 2,500 V/cm torr, B is 1000 G, and the filling pressure p is 10 mtorr.

In the first place, classical ambipolar diffusion velocity v_a is estimated. The ambipolar diffusion coefficient D_B^a across the magnetic field is given by

$$D_B^a = \frac{D_a}{1 + b_i b_e B^2} , \qquad (8)$$

where b_i and b_e are the ion and electron mobility and D_a is the ambipolar diffusion co-efficient without magnetic field. As is known,

$$D_a = \frac{T_e b_i}{e} .$$

Gerjouy and Stuart (1960) suggested that if the electrons lose their energy only through ionization,

$$T_e \cong \frac{E}{\alpha} = \frac{E/p}{\alpha/p} \, . \tag{9}$$

Using the value of α by Gerjouy and Stuart (1960), T_e becomes 500 eV under the condition stated above. Since Sand and Waidmann (1970) had detected the X-rays emitted during the break-down phase, the value of 500 eV is not a very unrealistic one. Therefore, the electron loss velocity v_a by ambipolar diffusion can be calculated by the relation

$$v_a = \frac{D_a^B}{a} \, .$$

In this case v_a is about 10^3 m/sec*, and $\tau_c (\sim a/v_a)$ become 30 μsec. Since τ_i is about, 0.1 μsec*, $\tau_c \gg \tau_i$ holds. Therefore, the classical ambipolar diffusion does not have any significant contribution to the break-down process.

Because the discharge tube is bent into the torus, the toroidal drift of electron and resulting E × B drift will be a more drastic loss mechanism. The loss velocity of this process is given as

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* For calculating these values, following electron-neutral and ion-neutral collision frequency (Brown, 1965) and ionization frequency (Gerjouy and Stuart, 1960) are used $\nu_{en} = 6 \times 10^9\ p\ \mathrm{sec}^{-1}$. $\nu_{in} = 10^8\ p\ \mathrm{sec}^{-1}$. $\nu_i = 10^9\ p\ \mathrm{sec}^{-1}$.

$$v_d = \frac{T_e}{eRB} + \frac{T_e \Delta t}{m_i R} \frac{1}{\left(\frac{\varepsilon_0 B^2}{nm_i} + 1\right)} \tag{10}$$

by simple re-arrangement of the results of Longmire (1967). The first term on the right-hand side of eq. (10) is the toroidal drift velocity and the second term is E × B drift velocity. Here, Δt is the build up time of the charge across the discharge tube and $\Delta t \simeq \tau_B$. Here, standard notations are used for the torus curvature, density of the plasma, dielectric constant of the vacuum and ion mass. Since the initial plasma density can be estimated to be $10^8 \sim 10^9$/cc by the help of eq.(1),(2) and (3), v_d is calculated to be 1.2×10^5 m/sec. Therefore, τ_c determined by the drift motion is 0.25 μsec. This is comparable to τ_i($\sim$ 0.1 μsec).

Although the loss due to the drift motion is large, the experimental results can not be explained only by this process. For instance v_d is a monotonic decreasing function of B, which means that τ_B decreases monotonically with B. In the experiment, however, τ_B turns to increase above 1000 G, so that another mechanism must be considered to explain the observed results.

The possible mechanism would be the turbulent diffusion caused by the drift dissipative ion acoustic instability. This instability occurs in a sufficiently rarefied plasma where electron mean free path is not too small, and where the ion mean free path is large. In addition to this, the growth condition of the instability is written by the relation,

$$\frac{D_e}{a} \ll C_s \,,$$

where C_s is the ion sound speed . It can be said that the plasm, during break-down phase, satisfies all above conditions. Therefore, there is no reason why this kind of instability does not occur in our system. The growth rate γ of this instability, when the longitudinal current presents, is given by Kadomtsev (1965) as follows.

$$\gamma = [(\frac{au}{D_e})^2 \frac{\Omega_e}{\nu_{en}}]^{1/4} \frac{C_s}{a} \,. \qquad (11)$$

Here, Ω_e is the electron cyclotron frequency. The factor

$$((\frac{au}{D_e})^2 \frac{\Omega_e}{\nu_{en}})^{1/4}$$

is the extra one due to the longitudinal current. Using this growth rate, loss velocity v_{is} by ion sound instability becomes

$$v_{is} = \sqrt{\frac{aeE}{m_i}} (\frac{e}{m_e \nu_{en}})^{1/4} B^{1/4} \,. \qquad (12)$$

For the condition stated before, E becomes 25 V/cm, since

$E/p = 2.5 \times 10^3$ and $p = 10^{-2}$ torr. These value make v_{is} to be 2.7×10^{-5} m/sec, so that τ_c is estimated to be about 0.1 μsec. As τ_c is comparable to τ_i, this mechanism can not also be neglected. It is noted that v_{is} increases with $B^{1/4}$, which seems to give the explanation of the observed slow increase of Δt_B above 1000 G.

Because v_d and v_{is} are comparable each other, the more realistic form of the loss velocity will be $v_d + v_{is}$. If the loss velocity is assumed to be $v_d + v_{is}$, qualitative explanation of the curve of Δt_B against B seems to be possible. That is, so long as B is weak, the dominant loss process is the toroidal drift which decreases approximately as 1/B, whereas, it turns into the turbulent diffusion due to the ion acoustic instability above certain value of B. In fact, the value of B giving minimum τ_B is calculated to be 1200 G from the relation,

$$\frac{d}{dB}(v_d + v_{is}) = 0 . \tag{13}$$

The experimentally observed value in Fig. 9 is not far apart from 1200 G. When the plasma density is high, the approximate solution of the eq. (13) is written as

$$B_{min}^{5/4} = \frac{4T_e}{eR}\sqrt{\frac{m_i p}{aeE}}\left(\frac{1}{p^2}\,\frac{m_e \nu_{en}}{e}\right)^{1/4} . \tag{14}$$

Eq. (14) yields

$$B_{min} \propto (T_e(\frac{p}{E})^{1/2})^{4/5} \quad . \qquad (15)$$

It is found that B_{min}, the value of B which gives minimum Δt_B, changes only factor 2 even when E/p is varied from 500 to 5,000. This caluculaton seems to coincide with the experimental results in which the variation of B_{min} over E/p is not apparent (Fig. 9).

It is concluded from above discussion that by introducing two different electron loss mechanism qualitative explanation of the break-down characteristics for toroidal machine with high E/p state seems to be possible. The classical ambipolar diffusion which is often discussed elsewhere (Malesan et al, 1970. Rose and Clark, 1961) is too slow to fit the experimental results of our system.

§5. Conclusion

It is shown that electron beam injection into the torus provides very powerful tool for pre-ionization of a high β toroidal pinch system. The special electron gun capable of extracting more than 1 A is newly designed and tested successfully. This electron gun presents more powerful and simpler method of pre-ionization than the usual r.f. techniques. The application of the longitudinal magnetic field greatly reduces Δt_B and improves reproducibility of the discharge. In our case, it was possible to break-down the D_2 gas down to 2 mtorr by the help of the electron beam and longitudinal field.

Since the drift motion and the turbulent diffusion play an important role on the break-down, pre-ionization will be easier on a larger discharge system in which the loss rate of the electrons will be decreased due to the size effect. One of the reason why Sand and Waidmann (1970) can operate below 1 mtorr may be due to this size effect. This situation seems to have some resemblance to the break-down characteristics of the left hand part of the Paschen's minimum where easier break-down is attained for longer electrode distance.

Acknowledgement

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Captions of Figures and Tables

Fig. 1 Schematic drawing of the apparatus.

Fig. 2 A typical example of the output voltage of the r.f. oscillator.

Fig. 3 Schematic drawing of the pulsed high current electron gun developed during the course of this experiment.

Fig. 4 A typical example of the current wave form of the electron gun of Fig. 3. The peak current is 1 A in this case.

Fig. 5 A typical example of the azimuthal current and the one-turn voltage around the circumference of the torus. It is seen that the current and the voltage begin to rise and fall at the same time at the instant of break-down.

Fig. 6 Schematic drawing to define the break-down time Δt_B.

Fig. 7 Break-down time Δt vs pressure in the case when any pre-ionization techniques is not applied.

Fig. 8 Break-down time Δt_B against the time between the application of r.f. and the start of the main discharge. The operating base pressure is 10 mtorr and H_2 is used. The electron beam current is 2 mA and the shell potential is 2kV. The maximum r.f. voltage of 7kV is applied.

Fig. 9 Break-down time Δt_B vs toroidal magnetic field B.

The filling D_2 pressure is 8 mtorr. The charging voltage V_0 to the capacitor for toroidal electric field E is 15 kV and 10 kV for (a) and (b), respectively.

Fig. 10 Break-down time Δt_B against E/p. In this case, the filling pressure is kept constant and only the charging voltage to the capacitor is changed.

Fig. 11 Waveform of plasma current and double probe's ion=suturation current during pre-heating. The maximum plasma current in this case is 7.3 kA with the toroidal field B being 0.96 kG. The filling pressure is 8 mtorr.

Fig. 12 The electron density and ionization percentage against filling D_2 pressure. The accurate density measurement is possible after the decay of the current. The written curve is the data taken 25 μsec after the start of the current. In this case, the peak current is 7.3 kA and B = 960 G.

Table 1 The influence of break-down time Δt_B on the pre=ionization technique applied. In this case, the filling pressure is 15 mtorr, electron beam current is 150 μA, shell potential is +2kV and B = 1.5 kG. The frequency of the r.f. generator is 5 MHz and the peak voltage is 5 kV.

Table 2 The effect of electron beam current on the break=down time Δt_B. The filling pressure is 10 mtorr and B = 1.5 kG.

Table 3 Shell potential vs break-down time. The operating gas is H_2 filled to 15 mtorr and B = 1500 G. The term "float" means the case when the shell potential is floated by taking off all the wires connected to the shell.

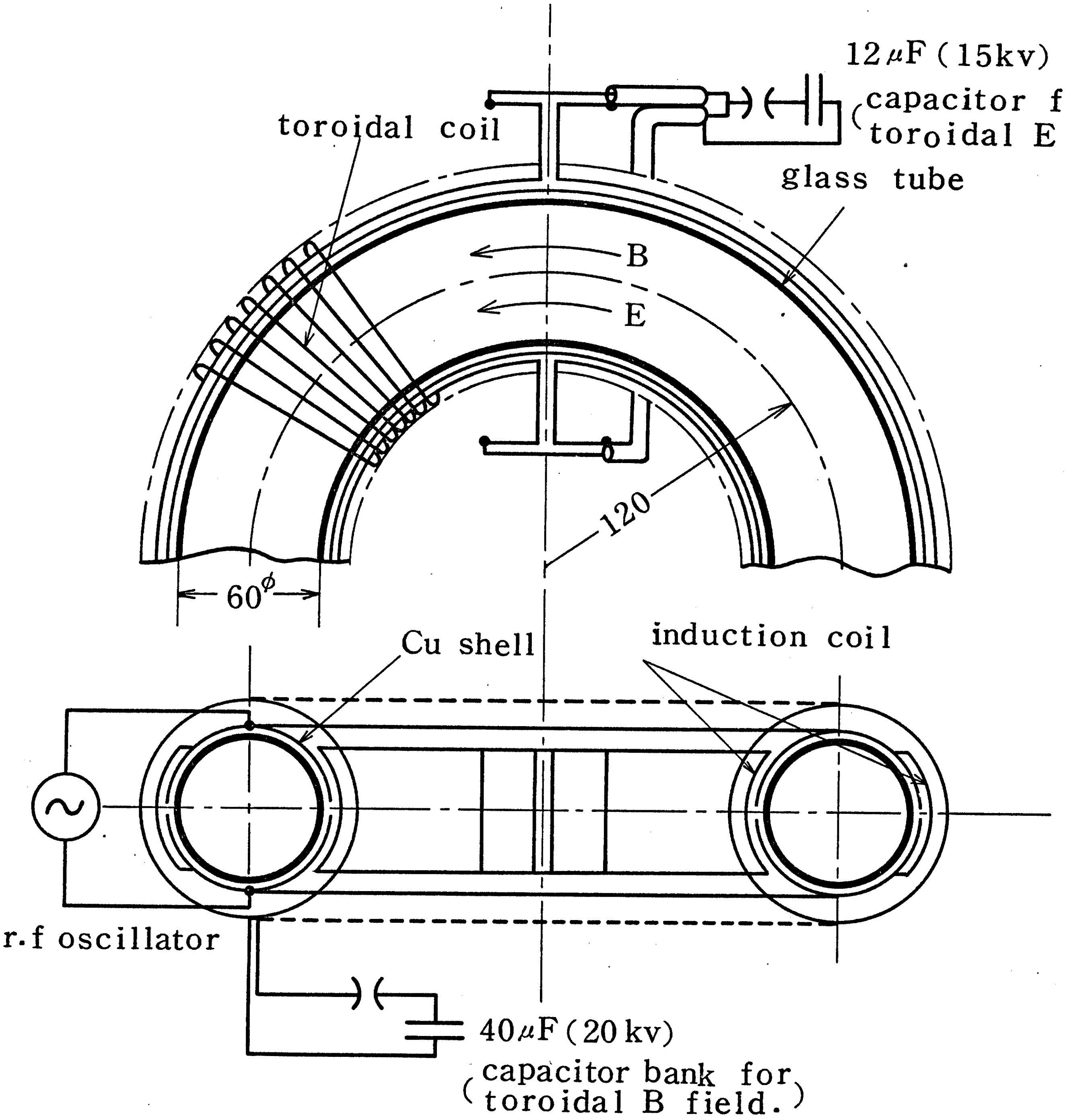
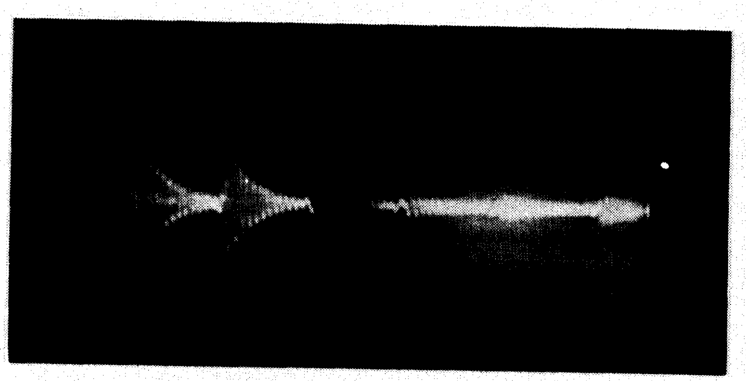

12μF (15kv)
(capacitor for toroidal E field)
toroidal coil
glass tube
B
E
120
60$^{\phi}$
Cu shell
induction coil
r.f oscillator
40μF (20 kv)
(capacitor bank for toroidal B field.)

FIG. 1



2μ sec/div

Fig. 2

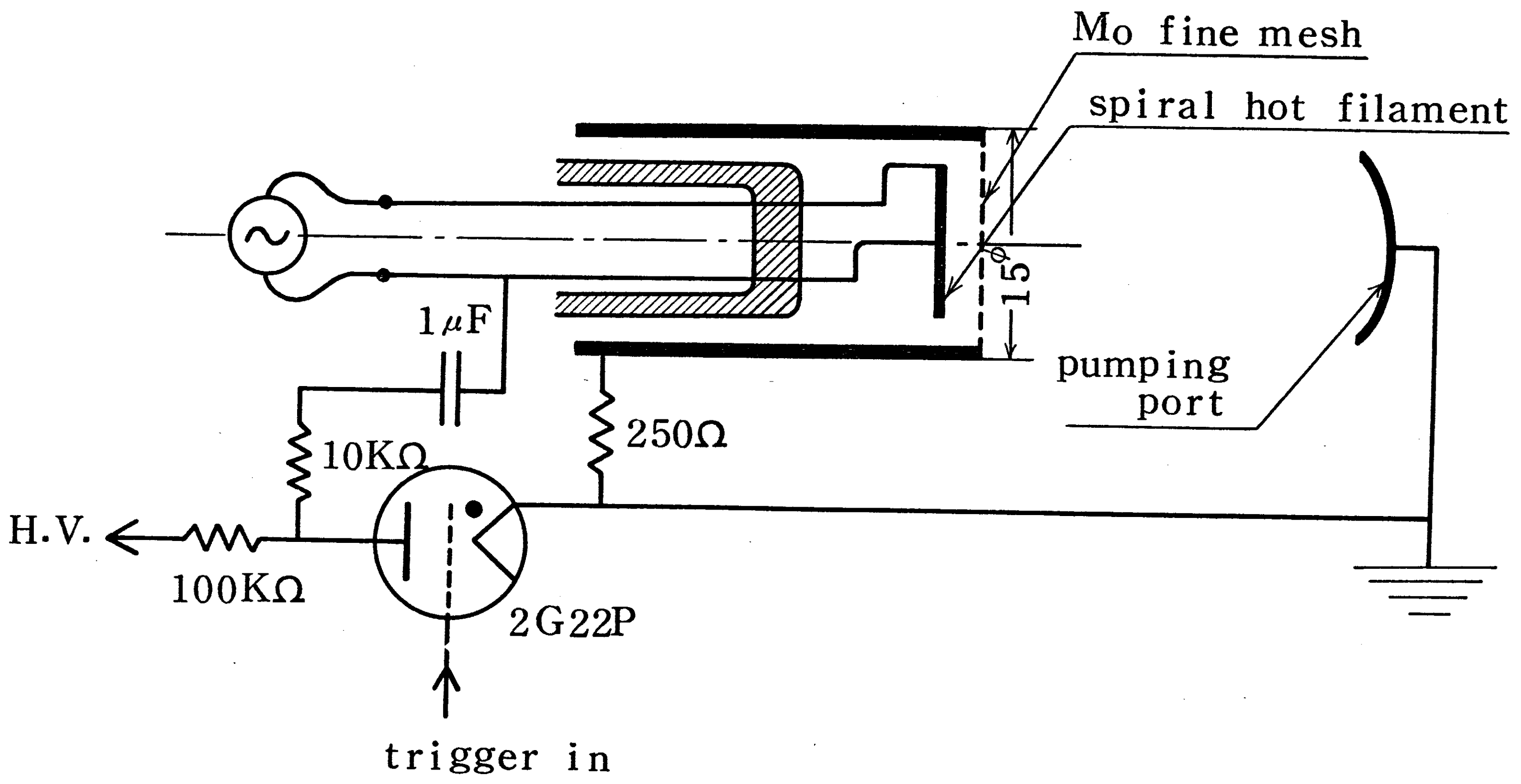

Mo fine mesh
spiral hot filament
15φ
pumping
port
1μF
10KΩ
250Ω
H.V.
100KΩ
2G22P
trigger in

FIG. 3

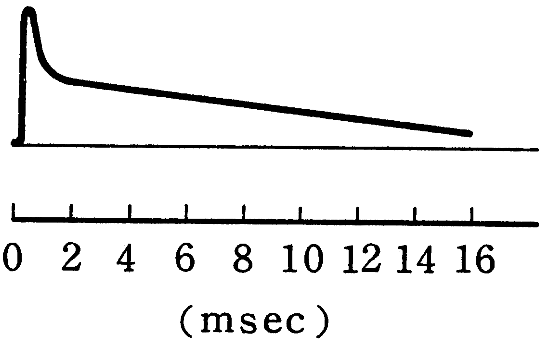


FIG. 4

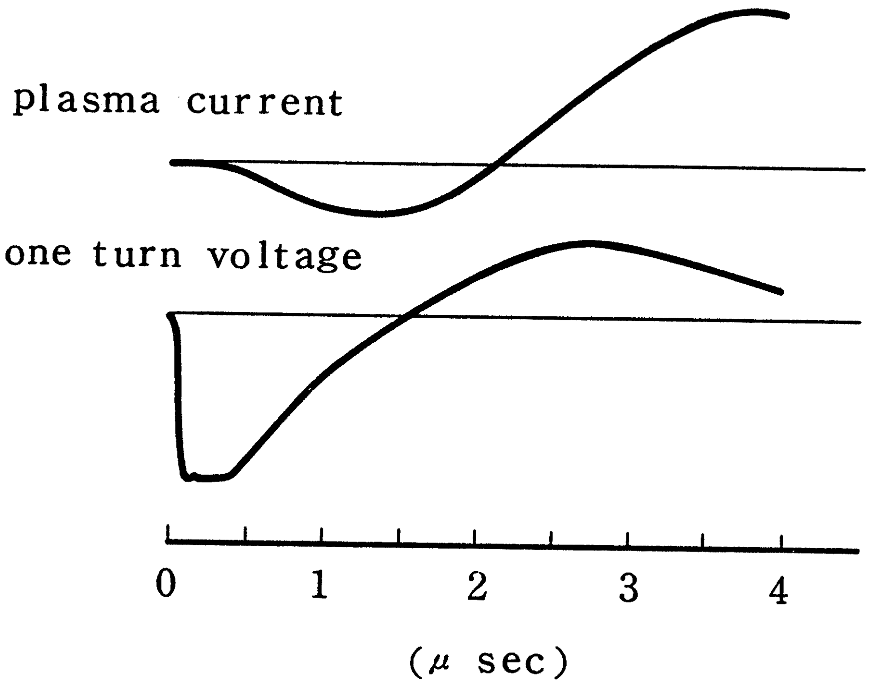


FIG. 5

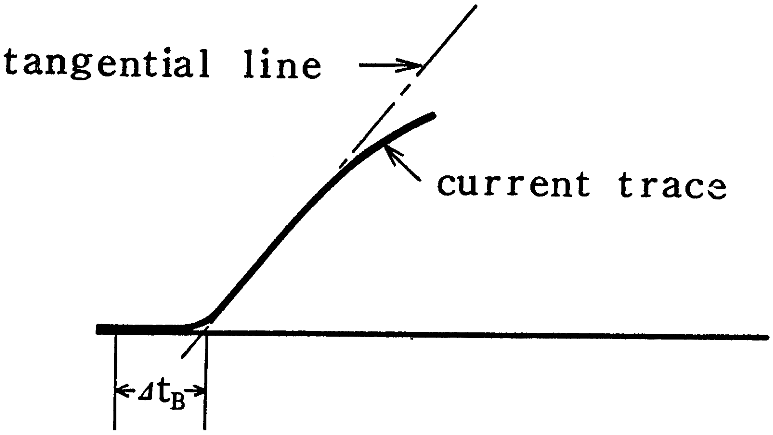


FIG. 6

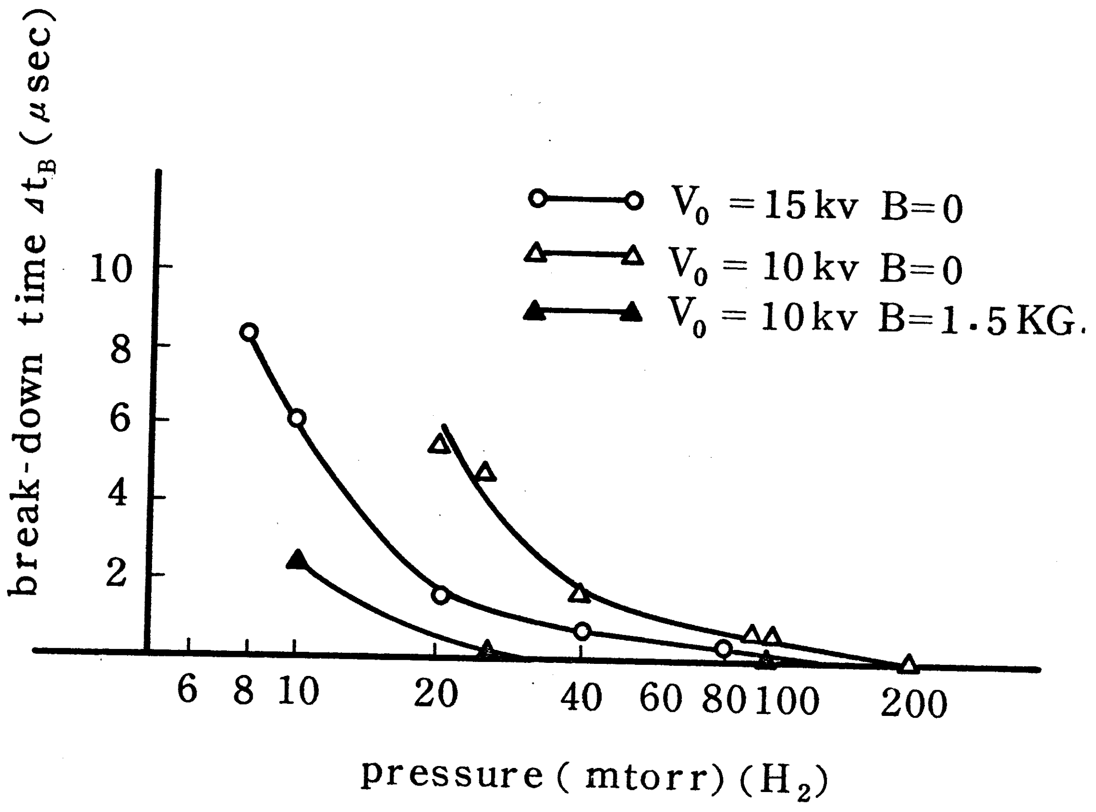

break-down time Δt_B (μsec)
10
8
6
4
2
6
8
10
20
40
60
80
100
200
pressure (mtorr) (H_2)
V_0 = 15 kv B=0
V_0 = 10 kv B=0
V_0 = 10 kv B=1.5 KG.

FIG. 7

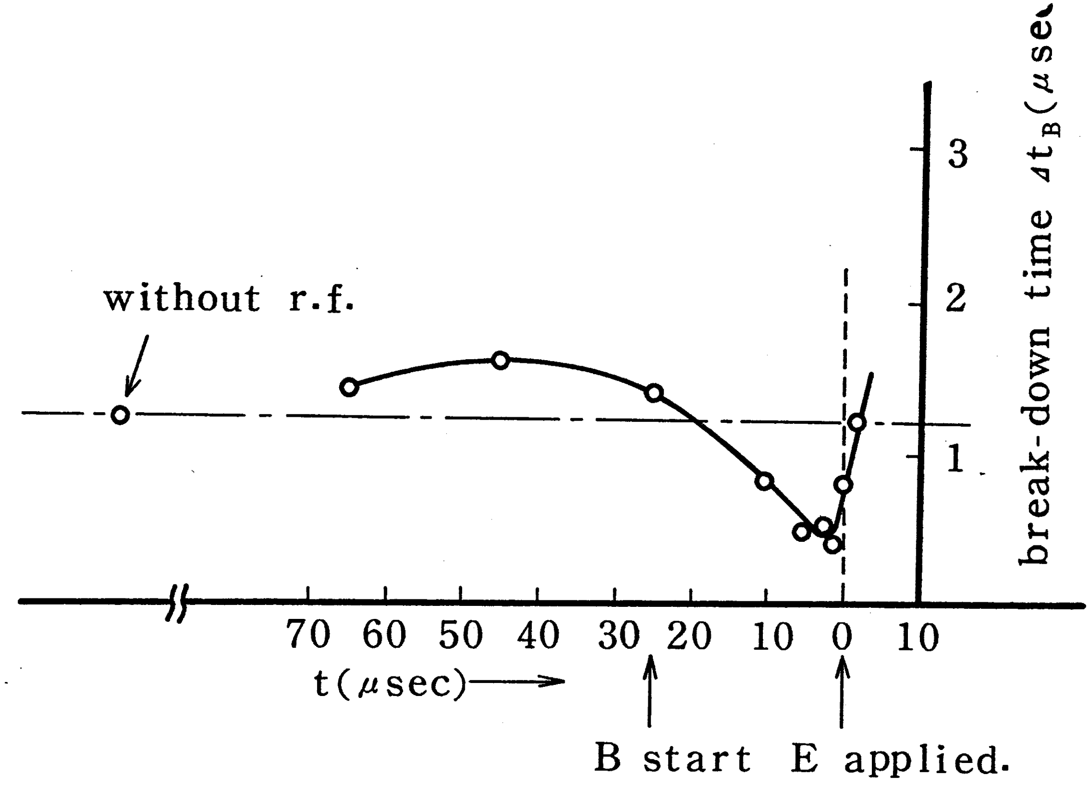

without r.f.
break-down time Δt_B(μse
3
2
1
70 60 50 40 30 20 10 0 10
t(μsec)
B start
E applied.

FIG. 8

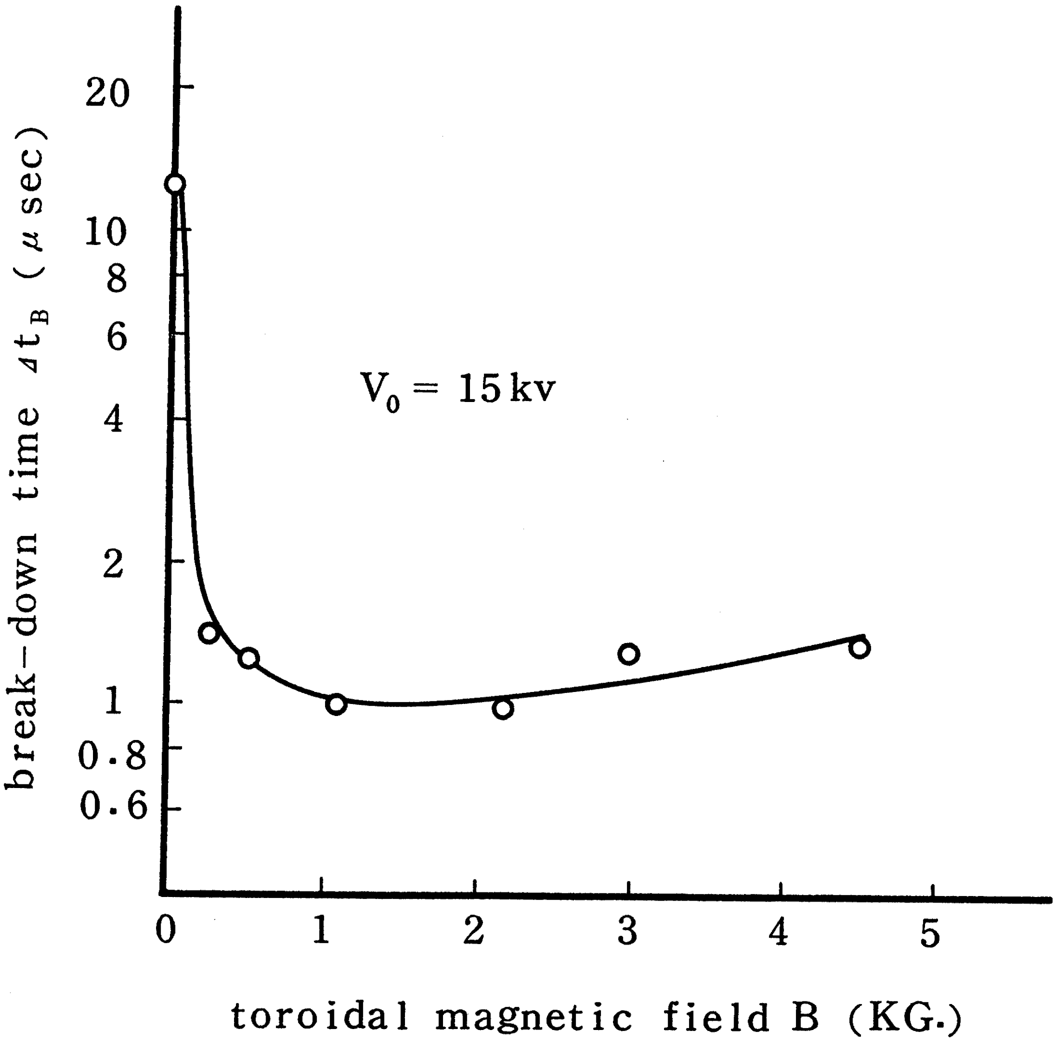

20
10
8
6
4
2
1
0.8
0.6
break-down time Δt_B (μ sec)
V_0 = 15 kv
0
1
2
3
4
5
toroidal magnetic field B (KG.)

FIG. 9(a)

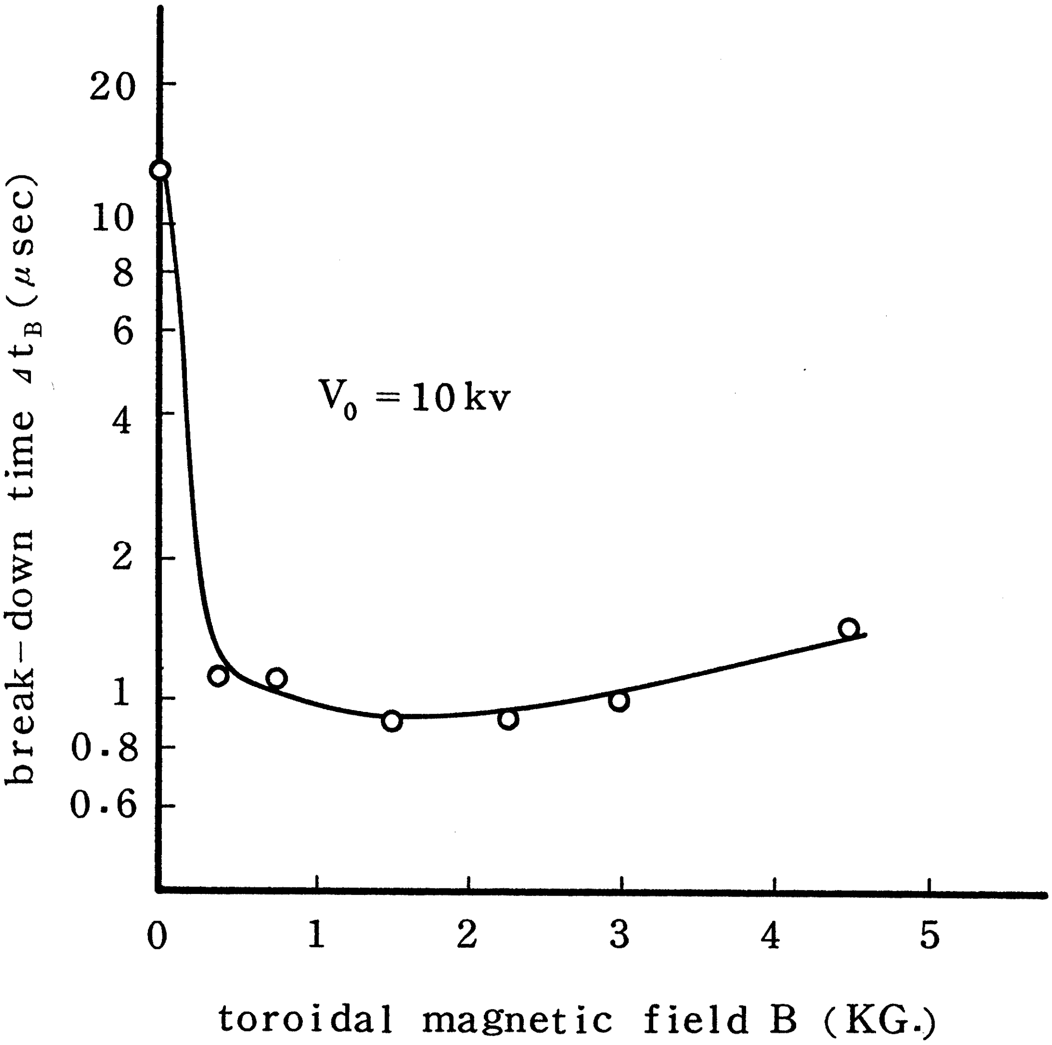

20
10
8
6
4
2
1
0.8
0.6
break-down time Δt_B (μsec)
$V_0 = 10$ kv
0
1
2
3
4
5
toroidal magnetic field B (KG.)

FIG. 9(b)

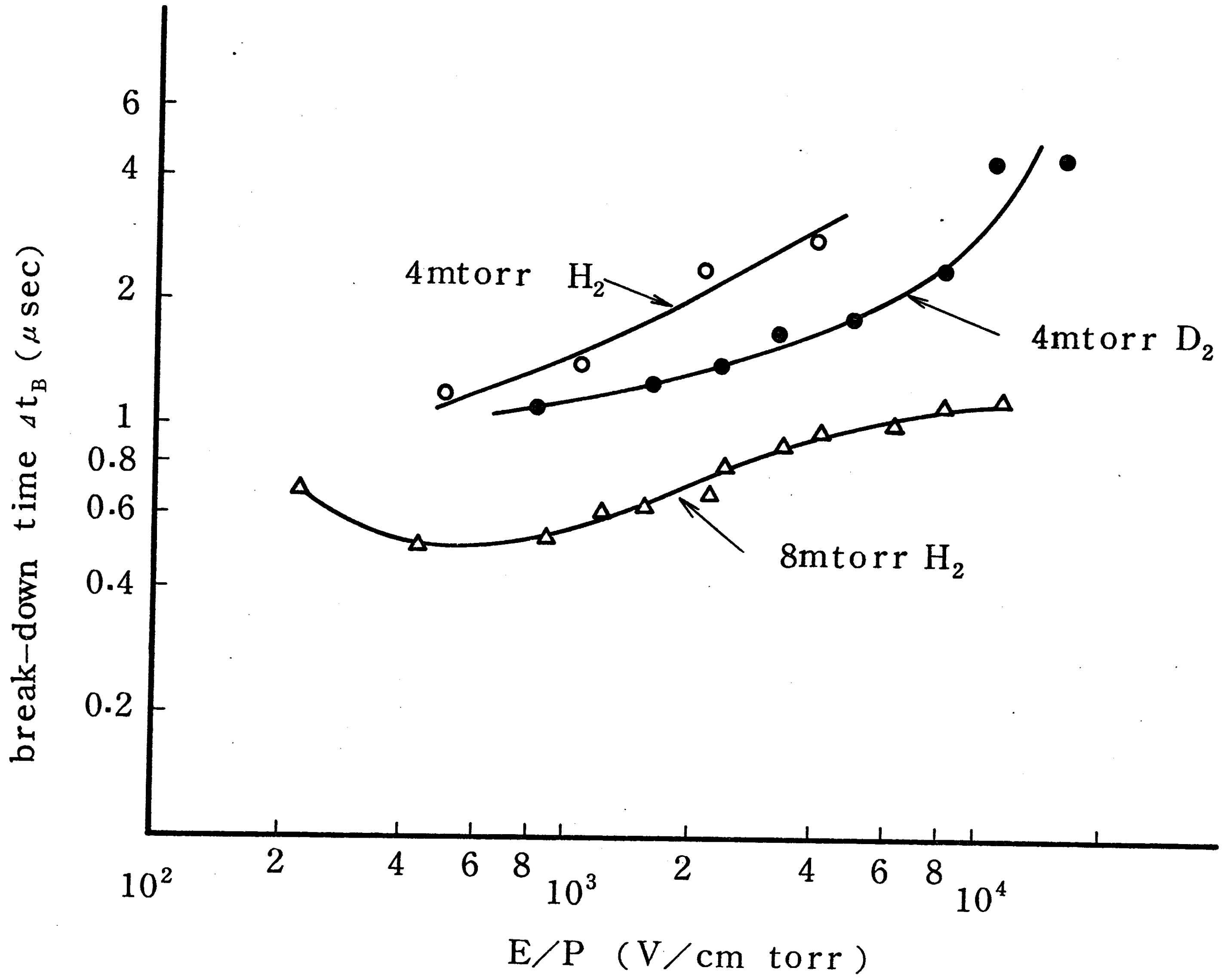

6
4
2
1
0.8
0.6
0.4
0.2
break-down time Δt_B (μsec)
4mtorr H2
4mtorr D2
8mtorr H2
10^2
2
4
6
8
10^3
2
4
6
8
10^4
E/P (V/cm torr)

FIG. 10

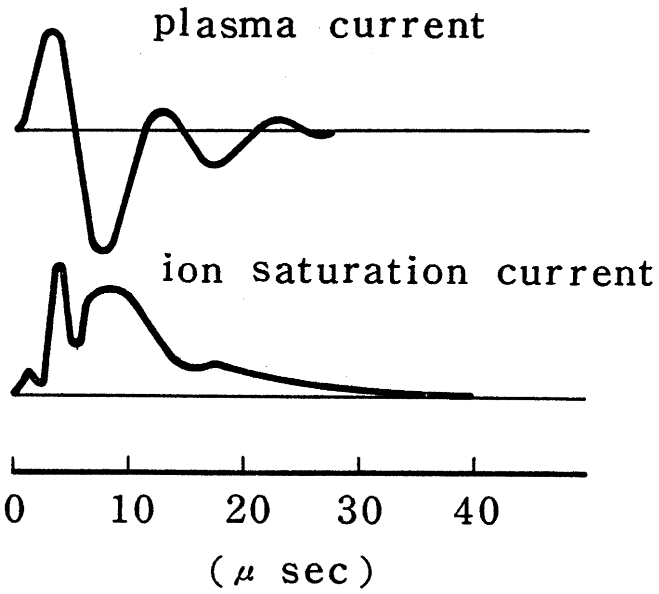


FIG. 11

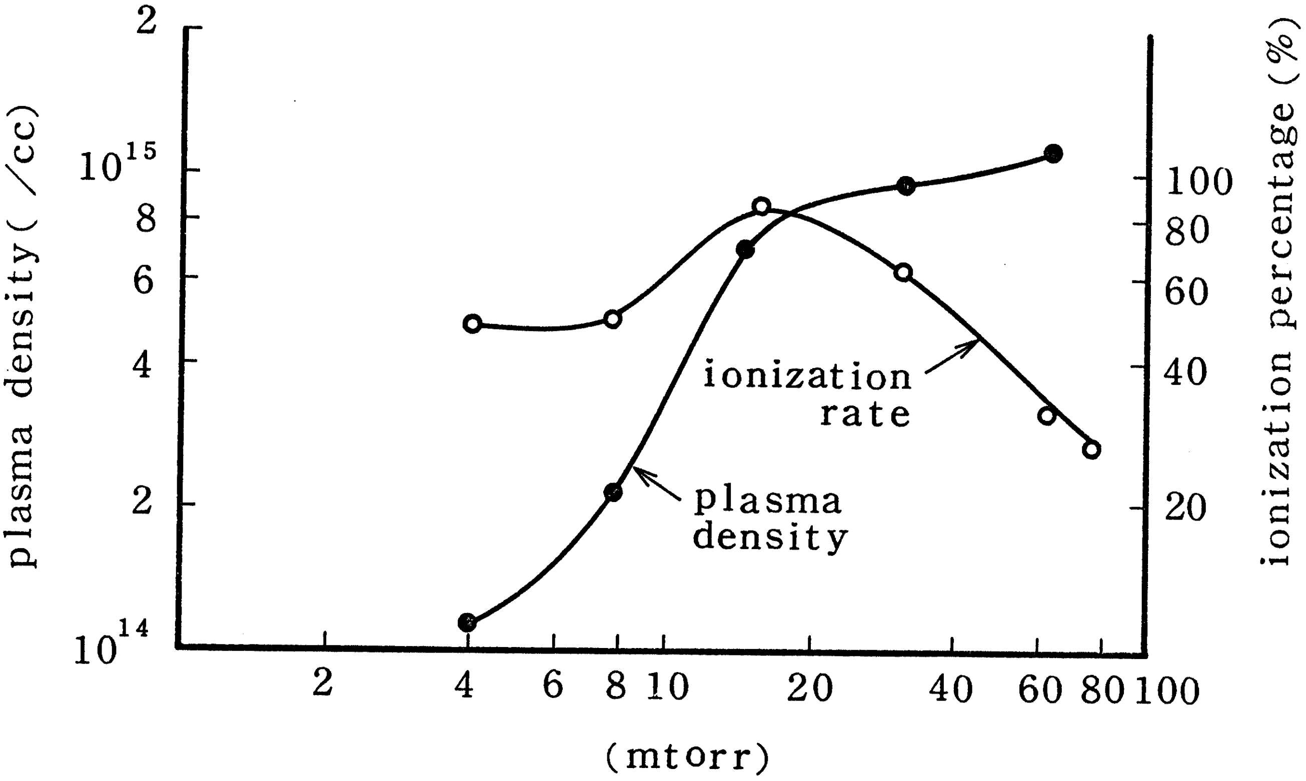

2
10^{15}
8
6
4
2
10^{14}
plasma density (/cc)
100
80
60
40
20
ionization percentage (%)
2
4
6
8
10
20
40
60
80
100
(mtorr)
ionization rate
plasma density

FIG. 12

applied techniques			break-down time Δt_B (μsec)
r.f.	electron beam	shell potential	
			1·2 ~ 1·6
○			1·4 ~ 1·6
○	○		0·6
	○		1·1
		○	1·2
	○	○	1
○	○	○	0·4

TABLE 1

electron beam current (mA)	break-down time Δt_B (μ sec)
0	no break-down
0·15	1·8 ~ 2·1
2	1·4

TABLE 2

shell potential (kv)	break-down time Δt_B (μ sec)
0	1·5
+ 1·5	1·0
− 1·5	1·4 ~ 1·6
float	1·5

TABLE 3