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On the effect of a longitudinal magnetic field on oscillatory characteristics of a subnormal region in discharge in argon

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Abstract. Oscillating nature of current pulses under d.c. excitation in subnormal region with longitudinal magnetic field at pressure range 0.20 torr to 0.85 torr have been studied. The frequency, bandwidth, peak–peak voltage, cut-off current and rise time of the current pulses have been observed with pressure, average tube current and magnetic field. A study of these oscillograms in magnetic field, average tube current and pressure are presented. The probable mechanism for the generation of oscillation based on space-charge field modification with magnetic field is discussed.

Keywords. Subnormal region; bandwidth; peak–peak voltage; cut-off current and rise time.

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1. Introduction

In the subnormal discharge the current–voltage characteristics has a negative slope [1] and the oscillatory characteristics of a low pressure d.c. discharge in air have been carried out by Nima [2], Jana [3] and inert gases by Emeleus [4]. Ward [5] showed that the experimentally observed negative resistance characteristics can be fitted in theoretical equations obtained by modified Townsend's basic equations in conjunction with the space-charge effect. However, very little work has, however, been done on the oscillatory characteristics of a low pressure d.c. discharge in subnormal region. In order to study the effect of a longitudinal magnetic field on the oscillatory characteristics of a subnormal region it is proposed to study the variation of frequency, bandwidth, peak–peak voltage, cut-off current and rise time of current pulses in a longitudinal magnetic field at different pressure and average tube current.

2. Experimental arrangement

The method of observation of oscillatory characteristics in the subnormal region in discharge in argon is shown in figure 1. The discharge tube, a cylindrical pyrex glass tube of length 6 cm, inner diameter 4.35 cm with plane parallel copper electrodes of diameter

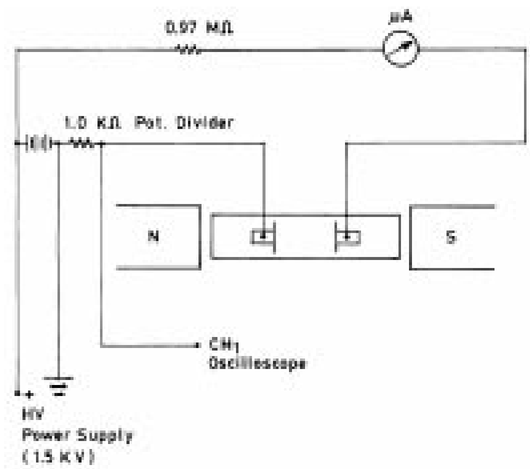

Figure 1. Circuit diagram for oscillations studies.

3.7 cm, gap 1.8 cm was thoroughly cleaned and properly aged for the purpose. The ballastic resistor 0.97 MΩ limited the average tube current and kept the HV unit within its current capacity. A 1 KΩ potential divider was connected between the discharge tube and earth to provide a signal to the oscilloscope (60 MHz digital storage, PM 3350, Phillips). A current meter (sensitivity $\pm 0.25\,\mu$A) was connected to measure the average tube current, cut-off current in the circuit. The tube is placed within the pole pieces of 7.0 cm diameter of an electromagnet so that the lines of force are parallel to the axis of the discharge tube.

The electromagnet is energized by a stabilized power and the magnetic field has been measured by an accurately calibrated gauss meter (sensitivity 2%). The pressures of the gas were measured by a calibrated Mcleod gauge (sensitivity 0.05 torr). Spectroscopically pure argon was supplied by the British Oxygen Company.

3. Results and discussion

In the subnormal region, the discharge consists of current pulses or number of oscillations. Figure 1 shows the system used to measure the parameters of the oscillations. The oscillograms of current pulses with zero and finite longitudinal magnetic field, pressure and average tube current are shown in figures 2–4.

Figure 2 shows at fixed pressure 0.35 torr and average tube current $30\,\mu$A, the frequency as well as bandwidth increases but peak–peak voltage decreases with increase in magnetic field between 0 and 1850 G. The results are shown in table 1 for a constant current of 50 μA. In case of the longitudinal magnetic field the axial electric field and electron temperature decrease whereas the radial electron density increases and the discharge current gradually increases within a lower magnetic field and finally assumes a constant value [6]. It is known that for a fixed voltage the mobility of the positive ions along the magnetic field increases with magnetic field.

Therefore, the transit time goes no decreasing with increasing magnetic field. In fact from figure 5 it can be seen that the frequency is directly proportional to the magnetic field.

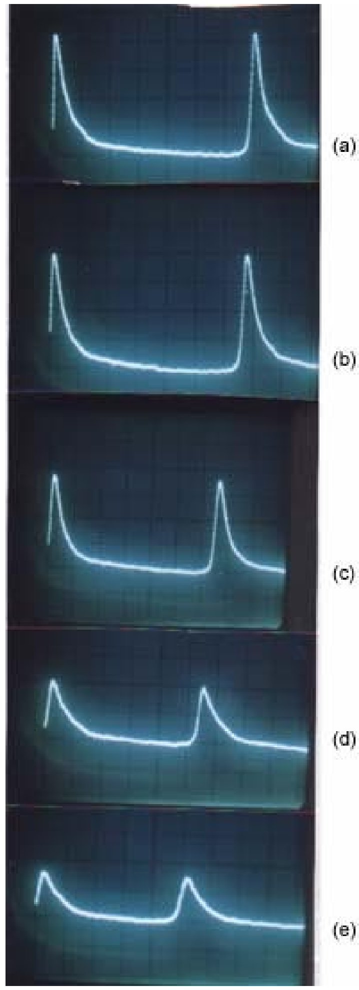

Figure 2. Oscillations of the current pulses with magnetic field. Oscillograms showing the increase in frequency and width with increase in magnetic field. The same base (20 μs/div) and sensitivity (0.1 V/div). Constant magnetic field (H): (**a**) 0 G, (**b**) 738 G, (**c**) 1110 G, (**d**) 1480 G and (**e**) 1850 G.

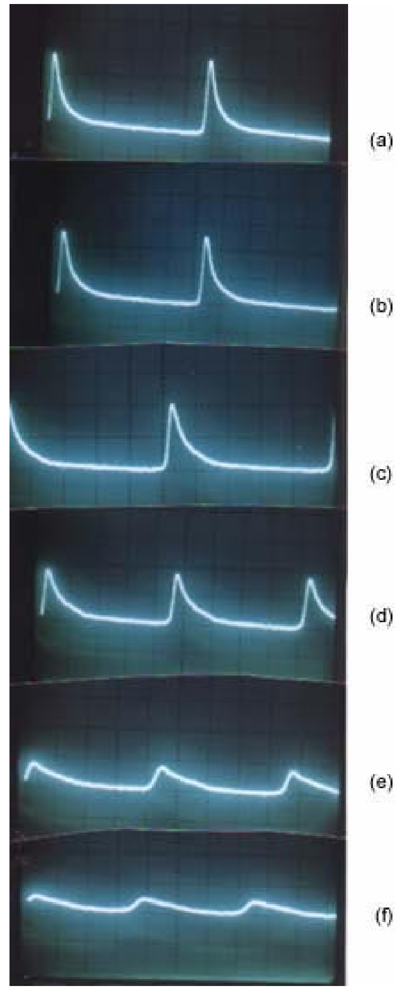

Figure 3. Oscillations of the current pulses with pressure. Oscillograms showing the increase in frequency, width and rise time with decrease in pressure. The same base (20 μs/div) and sensitivity (0.2 V/div). Constant pressure (P): (**a**) 0.525 torr, (**b**) 0.475 torr, (**c**) 0.400 torr, (**d**) 0.350 torr, (**e**) 0.300 torr and (**f**) 0.250 torr.

Figure 3 shows that at fixed average tube current 50 μA and magnetic field 18 G the frequency, bandwidth, rise time increase and peak–peak voltage decreases with the decrease of pressure between 0.525 torr and 0.250 torr. The results are entered in table 2 for a constant current of 75 μA. At a fixed voltage the mobility of the positive ions decreases as the pressure increases. As a result the transit time goes on increasing with increasing pressure. It can be represented by the relation

Table 1. Data of the oscillation parameters with magnetic field.

Pressure (P) (torr)	Average tube current (I) (μA)	Magnetic field (H) (in Gauss)	Frequency (f) (in kHz)	Width (ω) (μs)	Peak–peak voltage V_{PP} (in V)	Rise time t-rise (μs)
		0	10.8	5.0	455	6
		18	11.0	5.1	450	6
0.35	50	150	11.2	5.3	438	6
		300	11.6	5.7	426	6
		450	12.1	6.2	412	6
		600	12.8	6.5	390	6

Table 2. Data of the oscillation parameters with pressure.

Magnetic field (H) (in Gauss)	Average tube current (I) (μA)	Pressure (P) (torr)	Frequency (f) (in kHz)	Width (ω) (μs)	Peak–peak voltage V_{PP} (in V)	Rise time t-rise (μs)
		0.525	10.7	4.0	560	3.0
		0.457	11.3	4.2	520	3.2
18	75	0.400	11.9	4.5	404	3.7
		0.350	12.2	5.4	372	4.0
		0.300	12.6	6.8	208	4.2
		0.250	14.0	7.2	136	4.5

Table 3. Data of the oscillation parameters with average tube current.

Pressure (P) (torr)	Magnetic field (H) (in Gauss)	Average tube current (I) (μA)	Frequency (f) (in kHz)	Width (ω) (μs)	Peak–peak voltage V_{PP} (in V)	Rise time t-rise (μs)
		10	6.73	8.75	144	3.5
		20	7.21	8.50	188	3.5
0.325	300	40	8.33	8.00	196	3.5
		60	10.0	7.75	208	3.5
		80	10.6	7.50	216	3.5
		100	11.2	6.75	240	3.5

$$f = [1/\mu p + C]^{1/2},$$

that the frequency is directly proportional to the reciprocal of the square root of the pressure, where μ is the mobility and hence the current, p (torr) is the pressure and C is a constant.

Figure 4 shows that at fixed pressure 0.325 torr and magnetic field 150 G, the frequency, peak–peak voltage increase and bandwidth decrease with change of average tube current between 10 μA and 100 μA. The results are entered in table 3 for a constant magnetic field of 300 G.

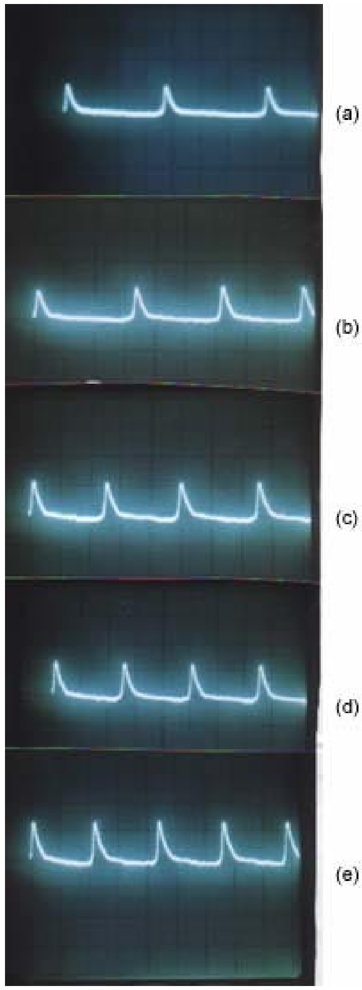

Figure 4. Oscillations of the current pulses with average tube current. Oscillograms showing the increase in frequency, peak–peak voltage, decrease in width with average tube current. The same base (50 μs/div) and sensitivity (0.2 V/div). Average tube current (I): (**a**) 10 μA, (**b**) 20 μA, (**c**) 46 μA, (**d**) 80 μA and (**e**) 100 μA.

The mechanism for the production of pulses involves [7] rapid ionization in the cathode region and the formation of a steep potential gradient relative to the positive column. The velocities of the positive ions change as they cross the negative glow while entering the cathode dark space. Therefore fluctuations in the discharge current occur with a frequency corresponding to the total time involved in the process, which largely depends on the movement and collision of positive ions. The increase in field in the cathode region also results in reducing the transit time at the positive ions, thus increasing the frequency with higher discharge current.

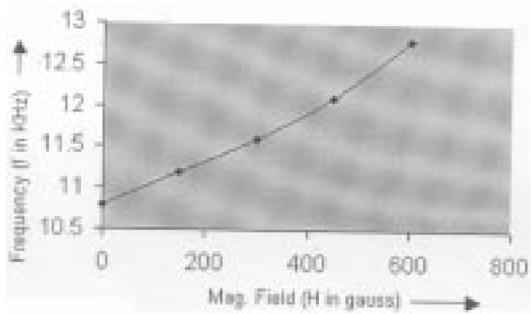

Figure 5. Variation of frequency with magnetic field with fixed pressure (P): 0.35 torr and average tube current (I): 50 μA.

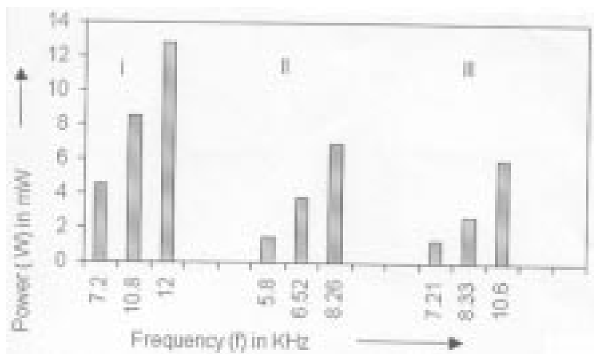

Figure 6. Power spectra of the ionization fluctuation with frequency, at $P = 0.35$ torr and (I) $H = 0$ G, (II) $H = 150$ G, (III) $H = 300$ G.

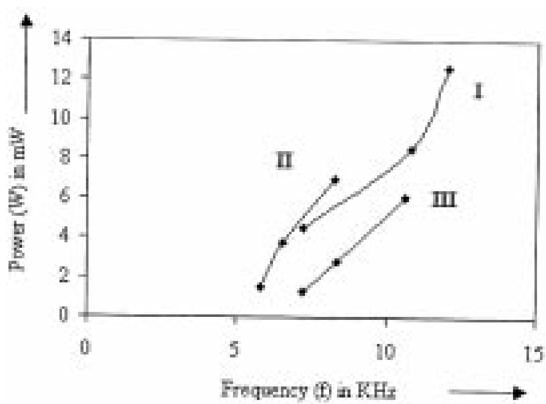

Figure 7. Variation of power with frequency at (P): 0.35 torr and (I) $H = 0$ G, (II) $H = 150$ G, (III) $H = 300$ G.

Figure 6 shows the power spectrum of the ionization fluctuations with frequency which appeared with magnetic field off and on at pressure 0.35 torr.

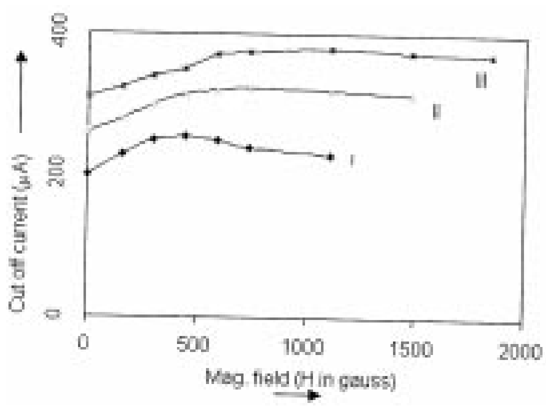

Figure 8. Change of cut-off current with magnetic field (0 and 1850 G) at constant pressure (P): (I) 0.50 torr, (II) 0.70 torr and (III) 0.85 torr.

Table 4. Comparison between the data's of the oscillation parameters with zero and finite magnetic field at constant pressure (P): 0.35 torr.

Magnetic field (H) (G)	Cut-off current (I_c) (μA)	Frequency (f) (kHz)	Bandwidth (ω) (μs)	Peak–peak voltage (V_{pp}) (in V)	Rise time t-rise (μs)
0	250	12.00	5.10	484	6.00
450	260	13.40	6.70	436	6.00

When the current is increased the wave form changes gradually and at the same time the period T of fundamental modes decreases. The corresponding frequency varies with $V * I$ (power) or I, since in the region under consideration the product of $V * I$ is a linear function at I.

Figure 7 shows the variation of power with frequency at fixed pressure 0.35 torr, with or without magnetic field.

Figure 8 gives the change of cut-off current with magnetic field at constant pressures of 0.5, 0.7 and 0.85 torr on the fundamental modes. The nature of the curve is the same for all the pressures shown and gradually rises at the cut-off current with the magnetic field attaining a maximum and then decreases, always shifting to higher magnetic field at a particular value of the same, when the pressure is increased.

In summary, comparison between the data's of the oscillation parameters in zero and finite magnetic field for a constant pressure of 0.35 torr are shown in table 4.

4. Conclusion

It is observed that the frequency, bandwidth of the current pulses and cut-off current are functions of magnetic field, pressure and average tube current. A qualitative explanation has been provided for the variation of the frequency, bandwidth, peak–peak voltage, cut-off current with magnetic field, pressure and average tube current. The increase in frequency, bandwidth and cut-off current with pressure, average tube current and magnetic field may be attributed to the fact that at relatively lower pressure, higher current and magnetic field characteristic loss time for ions and electrons is higher.

It can be concluded from our work with longitudinal magnetic field that the mechanism for the formation of pulse is due to the interaction of different elementary process which lead to different pulse regimes within one cycle of the oscillation. The discharge current acts as a control parameter for the structure of the current pulses. A change in structure is related to a change in the controlling of the elementary processes.

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