CHAPTER - IX

GENERATION OF ION-ACOUSTIC WAVE IN A GLOW DISCHARGE PLASMA BY SONIC TRANSDUCER : A NEW NONIMMERSIVE SONIC PROBE DIAGNOSTIC METHOD.

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9.1. INTRODUCTION

It was indicated previously (Chapter VII and Ghosal and Sen, 1976) that ion-acoustic waves are described by the charged particle density (or pressure) oscillations in which the ions and electrons are coupled to move in phase. Theoretically these were first predicted by Tonks and Langmuir (1929) on the basis of fluid analysis. It was found by them that for frequencies well below the ion-plasma frequency and assuming the perturbation to be isothermal the phase velocity (V_p) of ion wave should be given by

$$v_p = \sqrt{\frac{k(T_e + T_i)}{m_i}}$$

where the different terms are of usual significance. For these waves, though the longitudinal oscillation of "ions" are of importance, the fluid elasticity of the plasma is essentially determined by the temperature of the electron species for a laboratory plasma ($T_e \gg T_i$). This is as expected since the most significant part of the restoring forces which governs the propagation of ion sound wave is purely electrostatic in origin i.e. the coupling between the electrons and the ions arises from the electric fields resulting from charge separations.

Spontaneously produced ion acoustic wave was first experimentally observed by Revans (1933) for an ionized mercury vapour discharge. Latter Alexeff and Neidigh (1961) and Crawford (1961) observed ion waves which occurred naturally in the generation of gas discharges. The properties of the wave they observed were determined by the size of the plasma.

Hatta and Sato (1961) and Little (1961) were the first to excite ion acoustive waves externally. The dispersion of these waves were studied much conveniently since the waves were generated by external sources. Hatta and Sato were able to excite ion sound waves in a weakly ionized dark plasma electrostatically by the use of a meshed grid. They used Langmuir probe to detect the plasma density fluctuations due to the wave. Because of the low degree of ionization, a hydrodynamic treatment including ion-neutral collisions were required. Experimental results obtained therein showed good agreement for measurements of phase velocity at higher frequencies. The dispersion relation seemed to be apparently inadequate to explain the results of Hatta and Sato for lower frequencies. This discrepancy, however, was not explained by them. Even in an excellent review work on plasma waves by Sanderson (1974) this discrepancy was kept as an open question. However this can be explained in the following way : For their measurements Hatta and Sato did not possibly consider the possibility of forming standing waves. At higher frequencies the attenuation of the wave was high enough so that the wave reflected from the rear wall (or electrode) of the tube interfered little with the propagating wave. But for lower frequencies the damping was not that strong and the reflected wave is expected to strongly interfere with the wave generated by the excitor. Consequently the measured phase shifts being prone to errors, is expected to be smaller than its true value.

Little and his collaborators (Little, 1961, 1962; Little and Jones, 1965; Barret and Little, 1965) were able to excite ion acoustic waves with the use of an external coil which modulated the plasma density by varying the magnetic field. The plasma used in their experiments was a low pressure mercury arc. Compressional waves have been found to be transmitted along the cylindrical column of the plasma. The waves were demonstrated by a photomultiplier connected to a phase sensitive detector. Transmission has been observed from cut-off at 25 KHz. upto 50 KHz. corresponding to the wave lengths cut-off from 30 cm. to 3 cm. in the plasma. No damping has been reported. The principal drawback in this measurement was the presence of sizeable fluctuations in density.

Wong et al (1962, 1964), in their series of experiments, were able to remove this difficulty by using quiscent plasma for their measurements. They obtained a very stable plasma in a device known as Q-machine. In the Q-machine caesium and potassium atoms from an oven strike a hot tungsten plate and the alkali metal plasma is created by contact ionization. A second hot plate holds the plasma axially, and the plasma is further radially confined by using longitudinal magnetic fields. Since the plasma is produced near one end of the column the recombination losses effects a drift of plasma away from the producing plate. Accordingly they obtained two different phase velocities for two directions (for waves moving upstream and down-stream).

They were also able to excite and detect the ion waves electrostatically with grids placed perpendicular to the axis. The measurement of phase velocity and attenuation agreed fairly well with that expected from theoretical considerations.

Sessler and Pearson (1967) studied ion-waves for a r.f. discharge plasma. There also, the ion waves were excited electrostatically. They applied pulsed wave trains to a pair of closely placed parallel grids. Another similar pair of grids was employed to detect the cylindrical wave beam. They have reported measurements of the phase velocity and attenuation for frequency both smaller and larger than the ion plasma frequency.

As discussed in the previous chapter (Chapter VIII and Ghosal & Sen, 1977) that the propagation of acoustic wave through a weakly ionized plasma can be best understood by considering the plasma to be composed of two intermingled fluids viz. the ion fluid and the neutral particle fluid, the former of which can be considered to exist with its temperature elevated to that of the electron temperature. This ensures attenuation of acoustic waves at the plasma neutral gas, interfaces as observed by several authors ~~and~~ (Saxena & Gaur, 1969 and Gour & Saxena, 1970 etc.). In their methods the excitation and reception of the acoustic wave was done by transducers. This conforms the possibility of generation of ion-sound waves mechanically. This is expected since the coherent vibration of the neutral fluid particles induced by a loudspeaker may impart similar ion motions when the acoustive wave is made to cross a plasma neutral gas interface. In their measurements the wave was detected also by a microphone leading an impossibility to sort out the ion acoustic mode from the neutral acoustic mode. But if on the contrary the current perturbation arising from the ion motions due to the propagation of the ion-sound wave along the positive column could be picked up electromagnetically, the difficulty could be eliminated.

It will be shown in the following sections that it is possible to generate propagating ion acoustic mode within a plasma by a loudspeaker and the ion oscillations can be received electromagnetically to facilitate phase velocity measurements. In section 9.2 is given the necessary theory regarding the phase velocity measurements. In sections 9.3 and 9.4 the experimental arrangements and results are discussed. Experimental results have been found to be quite in agreement with the dispersion relation obtained theoretically in Chapter VII.

It has been observed that this new method for generation and reception of ion acoustive wave within a plasma may lead to a very reliable diagnostic tool since for the present method it is not necessary to disturb the plasma by inserting any probe into it.

9.2. THEORETICAL CONSIDERATIONS

As indicated in the previous section there is a possibility of generation of ion acoustic wave mode by the use of a loudspeaker. Let us, therefore recall the equation 7.16 of Chapter VII (and also Ghosal and Sen, 1976) for the formula for ion acoustive wave phase velocity v_p which is given by

$$v_p^2 = \frac{2 \dfrac{\gamma k \left(T_i + T_e\right)}{m_i}}{1 + \sqrt{1 + \nu_{pa}^2 / \omega^2}} \qquad .. (9.1)$$

where $\nu_{pa} = \nu'_{ia} + \frac{m_e}{m_i} \nu_{ea} = \frac{\nu_{ia}}{2} + \frac{m_e}{m_i} \nu_{ea}$

For ordinary laboratory gas discharge plasma the following approximations can be made,

$$T_e \gg T_i$$

and $\quad \nu_{ia}/2 \gg \frac{m_e}{m_i} \nu_{ea}$

If, further, the probe frequency $f = \omega/2\pi$ be chosen such that $\nu_{ia} \gg \omega$ the expression for v_p takes the simpler form;

$$v_p^2 = \frac{4 \gamma k T_e \omega}{m_i \nu_{ia}} \qquad .. (9.2)$$

The phase velocity of any propagating wave can be obtained in the following way :

Let us suppose the oscillation corresponding to the propagating wave can be picked up by some probe at two different positions along the discharge tube (the details of the pick-up arrangements will be discussed in the following section). Due to the finite propagation velocity the picked up oscillations may be expected to be mutually phase shifted. If τ' be the temporal phase shift for shifting the pick up device to a distance x, the phase velocity will be given by,

$$v_p = x/\tau' \quad .. \quad (9.3)$$

It sometimes becomes advantageous to measure the phase shift in the unit of mm. of the horizontal scale of a C.R.O. If we suppose the τ and T be the phase shift and period of oscillation in some convenient unit and τ' and T' be the corresponding quantities in section the following relation holds :

$$\frac{\tau'}{T'} = \frac{\tau}{T} \quad .. \quad (9.4)$$

$$\text{i.e. } \tau' = \frac{\tau}{T} T', \quad \text{where } T' = 1/f$$

From equation (9.3) and (9.4) one obtains,

$$v_p = \frac{x T}{\tau} f$$

Knowing T and τ from observations and also knowing x and f, v_p can be obtained experimentally.

9.3. EXPERIMENTAL ARRANGEMENTS AND METHODS

The method for the generation and measurement of ion-acoustic waves is discussed in detail in Chapter II. Therefore only a brief description will be given in the following :

The Schematic diagram of the experimental arrangement is shown in Fig. 2.9. The glow discharge plasma is generated in a glass tube (length 1 meter approx., diameter 6 cm.) by applying d.c. voltage to two hollow cylindrical brass electrodes (C and D) (electrode separation 45 cm) protruding from the tube wall. The plasma forms a column of about 50 cm. long and 5.5 cm. in diameter (i.e. the inner diameter of the tube, since no radial confinement has been done by utilizing longitudinal magnetic field).

As exciter of acoustic waves, we have used an electrodynamic loudspeaker (A) which has been placed within the discharge tube such that the acoustic wave is excited in the direction of the longitudinal axis of the discharge. Arrangements have been made so that the sonic wave passing through the discharge space might be picked up by means of the electrodynamic microphone (B) placed at the other end of the tube. This provision has been made keeping in view the idea (suggested by some authors) that effect of reflection of sonic wave at the plasma neutral gas interfaces on its propagation characteristics might lead to a good diagnostic technique. But our detailed theoretical calculations (Chapter VIII) has enabled us to believe that for laboratory glow discharge plasma, the reflection of sonic waves at the interfaces would produce little effect on its propagation characteristics. Hence the electrodynamic pick-up device, though depicted in the figure remains un-used for the present diagnostic studies. As mentioned earlier the wave mode, which would propagate in the medium of ionized particles, might produce an interfering alternating current of the same frequency. A laminated iron core Rogowaski ring (E) has been constructed (discussed in Chapter II) so that the magnetic field of perturbation current at a given point of the positive column may be picked up by it. The ring in effect serves the purpose of the secondary of a current transformer the primary of which being the positive column carrying alternating perturbation current.

Proper electromagnetic shielding arrangement has been made by surrounding the loudspeaker by the shielding box G, thereby the direct spurious pick up by the Rogowaski ring from the exciter is minimized.

The inductance of the Rogowaski ring has been made to form a tank circuit with a decade condenser box and the output is taken across the variable condenser so that in one hand, the greater sensitivity of the pick-up apparatus is obtained; and on the other hand, it becomes possible to filter out the required output from the actual discharge noise emitted. The output thus obtained is first amplified and then fed to an input channel of a double beam oscilloscope F, the other channel of which is fed by the audio-signal directly from the audio-oscillator. The reasons for application of the signal directly to the other channel of the C.R.O. are two fold. Firstly it sets the triggering sequence independent of the pick-up ring output thus avoiding spurious triggering (which may arise due to the emitted discharge noises) and secondly this signal can be used as the reference signal so that the phase shifts may be obtained faithfully.

Using the experimental device as described above (Fig. 2·9) the phase velocity of the wave mode propagating in the medium of the charged particles has been measured. The pick-up ring has been placed around the discharge tube for picking up the information of the alternating perturbed signal at different positions of the positive column of the glow discharge. The voltage induced in the ring at different positions are found mutually phase-shifted because of the finite propagation velocity of the wave. From the phase shift (T) measured by the C.R.O., the known distances (x) between the positions of the ring, and the frequency (f) of the signal, the phase velocity of the wave has been measured.

9.4. RESULTS AND DISCUSSIONS

Fig. 9.1 also table 9.1 shows the variation of voltage induced in the pick-up ring placed at a fixed position around the positive column on the pressure at three different discharge currents (5 mA, 10 mA and 20 mA) for the probe frequency 4.2 KHz. All measurements have been made keeping the gain of the amplifiers at a fixed level. Since for a qualitative study the actual voltage induced is of little importance we have expressed the voltage in terms of the peak to peak height of the waveform displayed by the C.R.O. in milimeters.

Table 9.1

Pressure in Torr.	Discharge current in mA.	Pick-up ring output (p-p) in mm.
0.05	5	25
	10	27
	20	28.5
0.07	5	30
	10	35
	20	37.5
0.09	5	33
	10	39
	20	42
0.10	5	34
	10	40.5
	20	43.5

It may be noticed from the graph (Fig. 9.1) that with increasing pressure the output increases; this is expected since pressure increases the acoustic power the Loudspeaker delivers. This conforms to our belief that the wave is purely mechanical in origin.

For the measurements of phase velocity of the wave the pick up ring was placed at a particular position (Pos.1) around the discharge tube near the loudspeaker end and then shifted to three other positions (positions 2,3,4) each being 5 cms. apart (away from the speaker) from the former. The temporal phase shifts τ have been measured in the unit of mm. of the horizontal scale of the C.R.O. for the shift of positions of the pick up ring. The values of τ against the positional shift of the ring has been inserted in Table 9.2, for four different probe frequencies. For these measurements the gas pressure has been kept 0.05 Torr. In figure 9.2 is plotted the τ/T values against the positional shift of the pick-up ring at four different frequencies. The straight lines clearly indicate the existance of a propagating wave with constant phase velocities along the positive column. In table 9.2 also inserted the phase velocities of the propagating wave at different frequencies keeping the pressure constant. The phase velocity has been calculated using the formula

$$v_p = \frac{x\, T\, f}{\tau}$$

As indicated previously, under the present experimental condition the phase velocity of ion acoustic wave is given by the formula

$$v_p^2 = \frac{4 \gamma k T_e}{m_i} \frac{\omega}{\nu_{ia}}$$

From the formula pressure remaining constant (i.e. for constant ν_{ia}) v_p^2 is expected to be proportional to probe frequency f . Thus, as can be seen from Fig. 9.3 depicting the variation of v_p^2 with frequency $\omega/2\pi$, the theory conforms the obtained experimental results. Since it is well known that at low energies the ion neutral atom collision cross-section is almost the same as the atom-atom cross section for most of the molecular gases, ν_{ia} can be calculated fromthe kinetic theory data available for air. Thus knowing ν_{ia} electron temperature has been calculated using the above equation (Table 9.2). The obtained electron temperature ($\simeq 1{\cdot}3 \times 10^4\,^\circ K$) agrees fairly well with the earlier data of electron temperatures available for the same discharge conditions.

The same measurements have been made at different pressures (Table 9.3) at a constant frequency. In figures 9.4 and 9.5 depicted the variation of square of phase velocity and electron temperature with gas pressure. Of them the former one conforms validity of equation 9.2. It can be seen from fig. 9.5 that as pressure increases the electron temperature

<u>Table 9.2</u>

f (kHz)	x (cm)	τ (mm)	T (mm)	τ / T	v_p (cm./sec.)	v_p^2 (cm^2/sec^2)	T_e (°K)
	5	9.5	50	0.19			
4.2	10	19	50	0.38	1.10×10^{5}	1.21×10^{10}	1.35×10^{4}
	15	28.5	50	0.57			
	5	11	50	0.22			
5.57	10	22	50	0.44	1.31×10^{5}	1.72×10^{10}	1.39×10^{4}
	15	33	50	0.66			
	5	14.5	50	0.29			
9.60	10	29	50	0.58	1.65×10^{5}	2.72×10^{10}	1.32×10^{4}
	15	43.5	50	0.87			
	5	17.5	50	8.35			
14.20	10	35	50	0.70	2.03×10^{5}	4.12×10^{10}	1.36×10^{4}
	15	42	40	1.05			

decreases. This can also be explained qualitatively by the fact that for higher pressures the decreased mean free path reduces the energy gained by the electrons from the supply field between subsequent collisions.

Table 9.3

f in KHz	Pressure in Torr.	τ (mm)	T (mm)	v_p (cm./sec)	v_p^2 (cm^2/sec^2)	T_e ($^\circ$K)
	0.05	28.5	50	1.10×10^5	1.21×10^{10}	1.35×10^4
	0.07	35	50	0.90×10^5	0.81×10^{10}	1.26×10^4
4.2	0.09	40	50	0.79×10^5	0.62×10^{10}	1.24×10^4
	0.10	42.5	50	0.74×10^5	0.55×10^{10}	1.23×10^4

Thus it is observed that propagation of sonic wave across a plasma-neutral gas interface induces ion-acoustic wave within the positive column of the discharge plasma. This ion-acoustic mode has been found to be propagating. This is expected since the ion-sound wave propagating away from the loudspeaker faces again a plasma neutral gas interface where the wave is strongly attenuated due to high mismatch of acoustic impedances of the fluids on both sides of the interface and thereby the possibility of forming standing wave is almost eliminated. This has also been seen that the ion-sound oscillations can be picked up electromagnetically by placing the probe externally around the plasma column. Thus for the present method both for generation and reception of ion-acoustic wave no actual insertion of probe into the plasma is necesary. This condition is very much desirable for diagnostic studies. Thus it may be said that our experiment presents a very convenient diagnostic technique for measurement of plasma properties.

REFERENCES

1. Alexeff, I. and Neidigh, R. (1963). Phys. Rev., 129, 516.
2. Barret, P.J. and Little, P.F. (1965). Phys. Rev. Letters, 14, 356.
3. Crawford, F.W. (1961). Phys. Rev. Letters, 6, 663.
4. Ghosal, S.K. and Sen, S.N. (1976). Proc. Ind. Nat. Sc. Acad., 42A, 336.
5. Ghosal, S.K. and Sen, S.N. (1977). ibid., 43A, 96.
6. Gour, S.C. and Saxena, A.P. (1970). Ind. J. Pure & Appl. Phys., 8, 271.
7. Hatta, Y., and Sato, N. (1961). Proc. Fifth International Conference on Ionization Phenomena in Gases, North Holland Publishing Co., Amsterdam (1962), Vol. I, 478.
8. Little, P.F. (1962). Nature, 194, 1137.

9. Little, P.F. (1961). Proc. Fifth International Conference on Ionization Phenomena in Gases, Munich (North-Holland Publishing Co., Amsterdam, 1962), Vol.II, 1440.

10. Little, P.F. and Jones, H.G. (1965). Proc. Phys. Soc. (London), 85, 979.

11. Revans, R.W. (1933). Phys. Rev., 44, 798.

12. Sanderson, J.J. (1974). Plasma Phys. edited by Kee, B.E., The Inst. of Phys., London and Bristol., Conference Series No.20, Chapter 3, p. 55.

13. Saxena, A.P. and Gour, S.C. (1969). Plasma Phys., 11, 611.

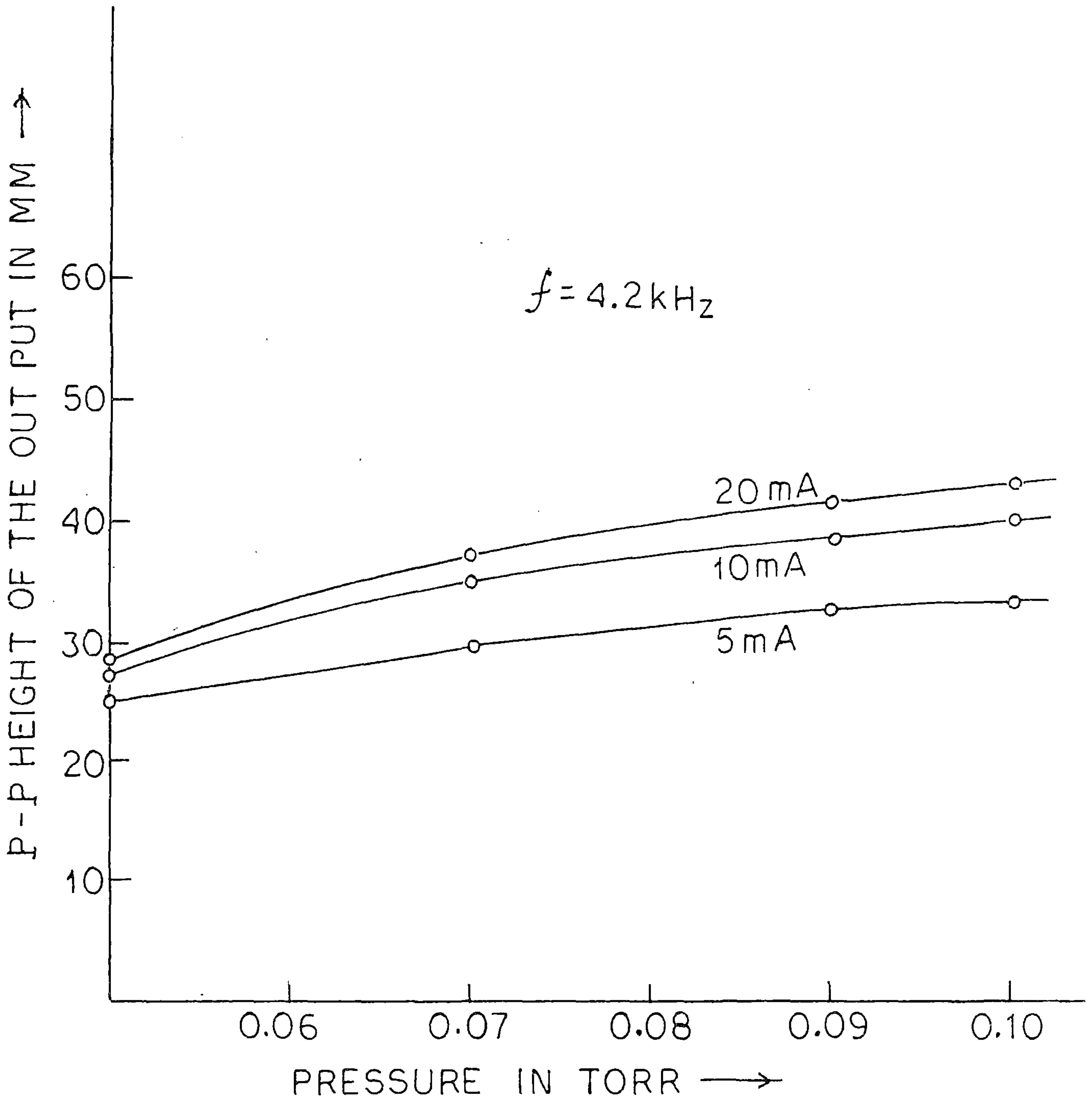
14. Saxena, A.P. and Gour, S.C. (1969). Int. J. Electronics, 27, 13.

15. Sessler, G.M. and Pearson, G.A. (1967). Phys. Rev., 162, 108.

16. Tonks and Langmuir, I. (1929). Phys. Rev., 33, 195.

17. Wong, A.W., D'Angelo, N. and Moteley, R.W. (1962). Phys. Rev. Letters, 9, 415.

18. Wong, A.W., Moteley, R.W. and D'Angelo, N. (1964). Phys. Rev., 133A, 436.



Variation of the Voltage picked up by the ROGOW Ring with air pressure at different discharge currents.

Fig. 9.1

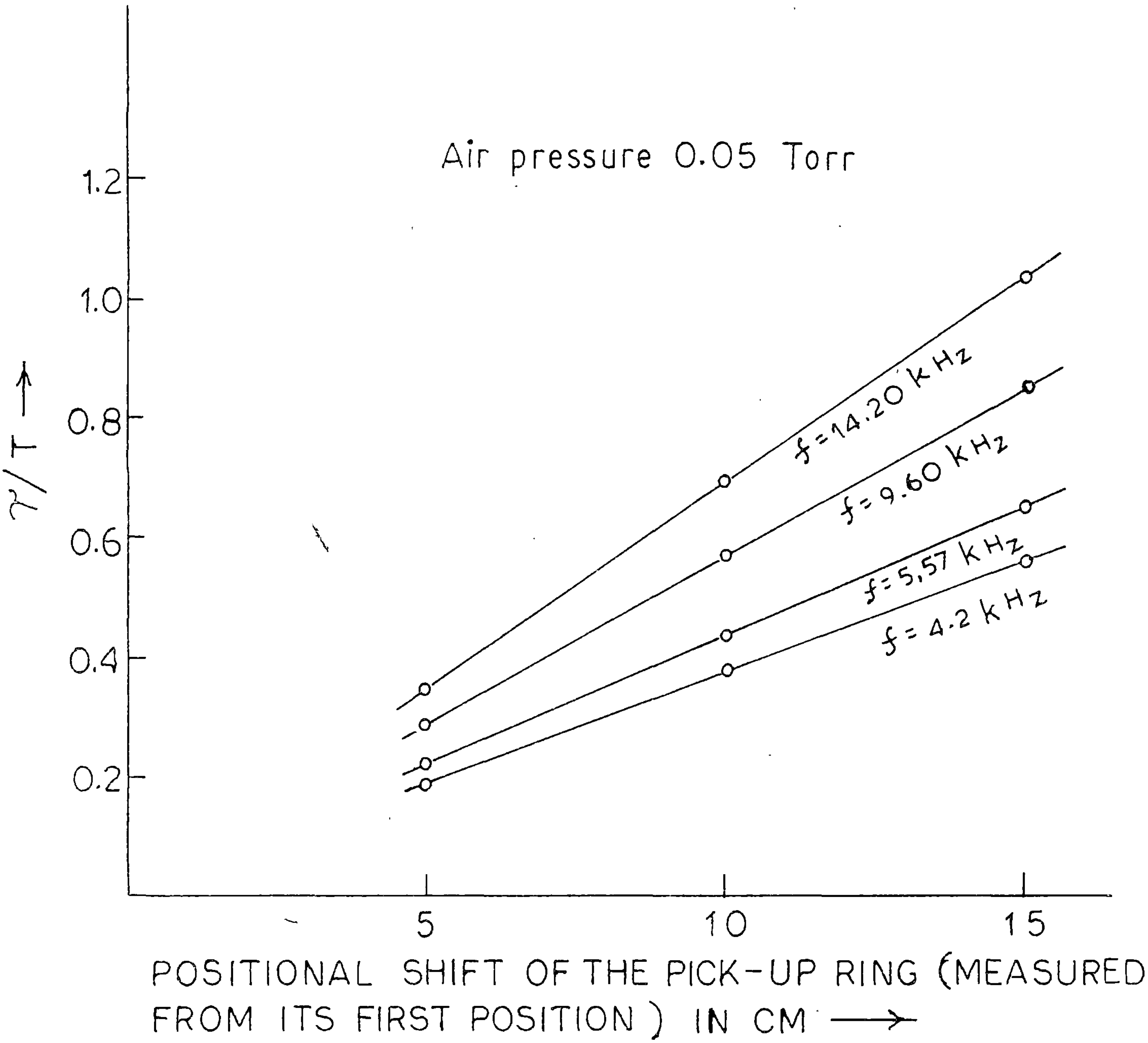
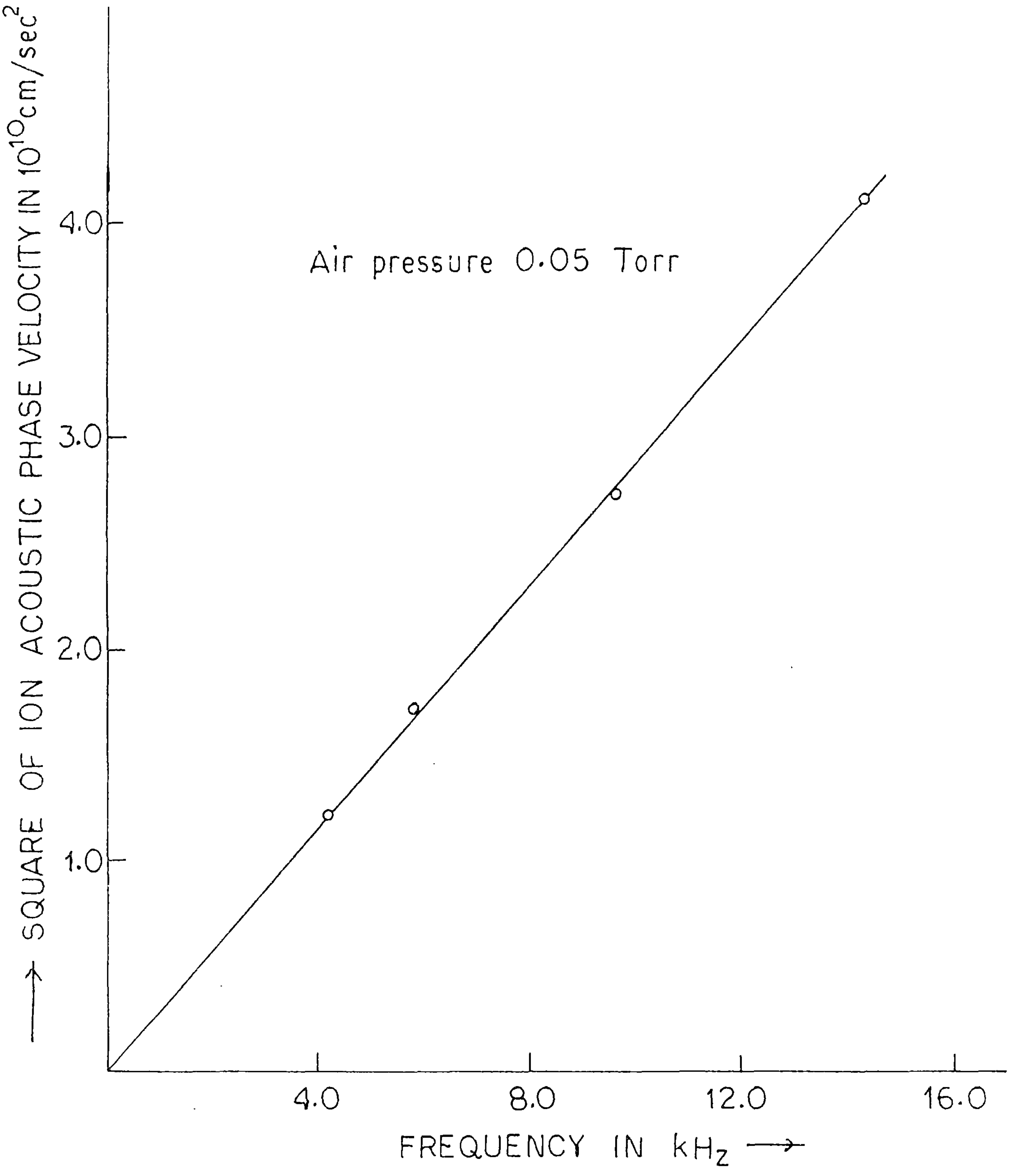

Air pressure 0.05 Torr
$\gamma/T \rightarrow$
1.2
1.0
0.8
0.6
0.4
0.2
5
10
15
f = 14.20 kHz
f = 9.60 kHz
f = 5,57 kHz
f = 4.2 kHz
POSITIONAL SHIFT OF THE PICK-UP RING (MEASURED FROM ITS FIRST POSITION) IN CM →

Fig. 9.2



Variation of Phase velocity of Ion Acoustic weve with frequeny.

Fig. 9.3

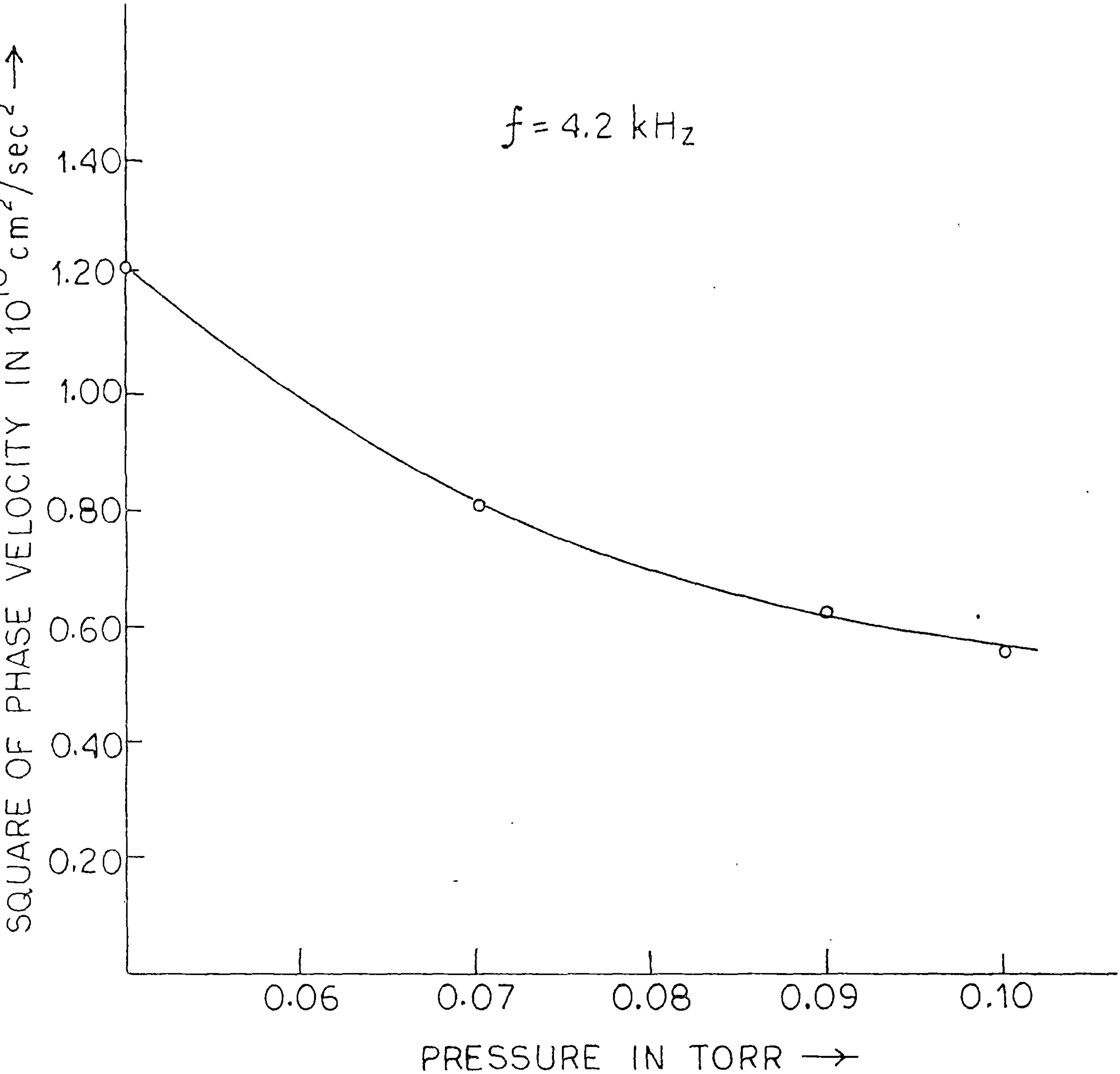

f = 4.2 kHz
SQUARE OF PHASE VELOCITY IN 10^10 cm^2/sec^2 →
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.06
0.07
0.08
0.09
0.10
PRESSURE IN TORR →

Fig. 9.4

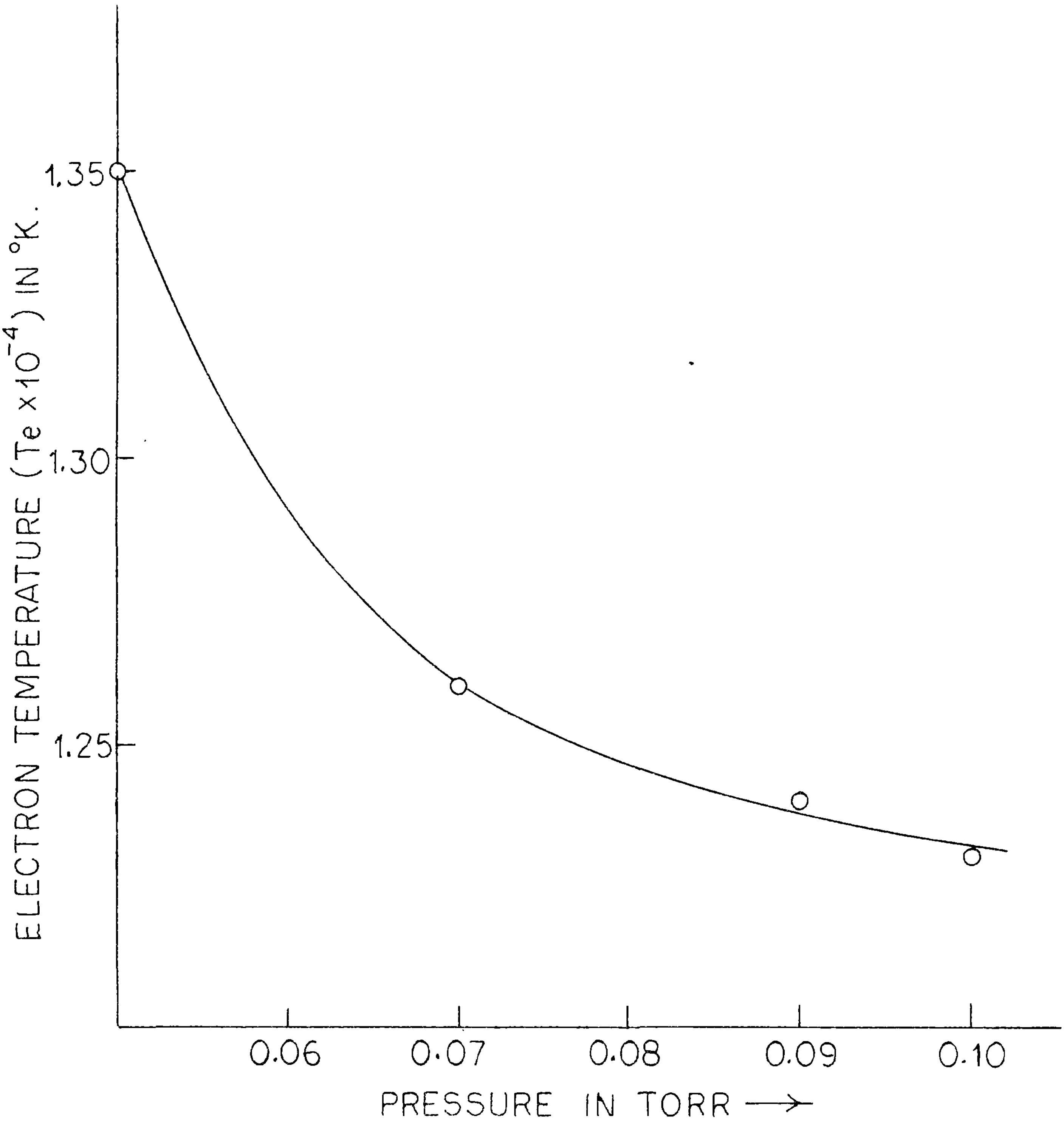

ELECTRON TEMPERATURE (Te x10^-4) IN °K.
1.35
1.30
1.25
0.06
0.07
0.08
0.09
0.10
PRESSURE IN TORR →

Fig. 9.5