Equilibrium Conditions Behind a Strong Shock Moving Through Argon

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IPP 3/11 Dezember 1963

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Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Institut für Plasmaphysik GmbH und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.

The thermodynamic data given for argon by Neumann and Knoche[1] have been combined with the strong shock equations in a manner identical to that used by Turner[2] in his hydrogen calculations. The thermodynamic data gives the state of the shock heated gas and the solution of the shock equations gives the shock velocity and initial pressure that would be required to produce this state. Multiple calculations provide sufficient data for cross-plots to be drawn and thus data to be obtained for specific values of initial pressure ahead of the shock.

The conservation equations for a strong shock take the form

$$\rho_0 v = \rho_1 (v - u) \tag{1}$$

$$P = \rho_0 v u + P_{str} \tag{2}$$

$$h_1 + \frac{1}{2}(v-u)^2 = \frac{1}{2} v^2 \tag{3}$$

where it is assumed that the initial pressure ahead of the shock is negligible in comparison with P, the total pressure including radiation pressure in the shock heated gas. Also it is assumed that the enthalpy per gram in the gas ahead of the shock is negligible in comparison with h_1, the enthalpy per gram, including radiation enthalpy, of the shock heated gas. ρ_0 is the mass density ahead of the shock, ρ_1 that behind. v is the shock velocity and u the flow velocity in the shock heated gas. P_{str} is the radiation pressure acting on the shock heated gas. It is assumed, contrary to the analysis of Sachs[3], that the mean free path of radiation is greater than the shock thickness. It is also assumed that the gas ahead of the shock does not absorb appreciable radiation, that is that the dimensions of the shock tube are much smaller than the mean free path of the radiation.

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1) Neumann, K.K. and Knoche, K.F. - Zahlendaten für Argon Plasma, Institut für Thermodynamik der Flugtriebwerke, Stuttgart

2) Turner, E.B. - Equilibrium Hydrodynamic Variables Behind a Normal Shock Wave in Hydrogen. Report No.GM-TR-o165-oo46o, Aug.26, 1958

3) Sachs, R.G. Physical Review 69, 514, 1946

Neumann and Knoche's tables give values for h_1, P, P_{str}, T_1 the temperature behind the shock and n the total number of particles per cm^3 in the shock heated gas. They also give values for r_e the fraction of n that are electrons, of r_o the fraction of n that are neutral argon atoms, of r_1 the fraction of n that are singly ionized argon ions, etc. In the present work r_i will denote these latter fractions, where i=o, 1, 2, ...

The variables that have been determined are n_e the electron density behind the shock from

$$n_e = r_e\, n \qquad (4)$$

and N the number density of heavy particles (atoms plus ions) behind the front from

$$N = n(1-r_e) \qquad (5)$$

Also when m is the mass of an argon atom it follows that

$$\rho_1 = mN \qquad (6)$$

Using Neumann and Knoche's notation of $P_m=P-P_{str}$, the material pressure behind the shock, it follows from equations 1 to 3 that

$$u = \sqrt{2(h_1 - P_m/\rho_1)} \qquad (7)$$

$$v = u + P_m/\rho_1 u \qquad (8)$$

$$\rho_1/\rho_o = \rho_1 vu/P_m \qquad (9)$$

Other variables determined are $r_o/1-r_e$ the fraction of the heavy particles that are argon atoms, $r_1/1-r_e$ the fraction of the heavy particles that are singly ionized argon ions, etc. Relations existing between r_o, r_1, etc. are

$$r_o + 2r_1 + 3r_2 + 4r_3 + \ldots\ldots = 1$$

and

$$r_e = r_1 + 2r_2 + 3r_3 + \ldots\ldots$$

and

$$r_o + r_1 + r_2 + r_3 + \ldots\ldots + r_e = 1$$

The results were obtained by solving equations 7 to 9, then both cross-plotting and interpolating to find values corresponding to P_o the pressure ahead of the shock of o.1, 1.o and 1o torr. The same procedure was used for determining the values of $r_o/1-r_e$, $r_1/1-r_e$, etc. Cross-plotting was not needed for the T_1 determinations. The results of these calculations are presented in Fig.1 to 5. The dependancy of P_m on shock velocity is given in Fig.2 for only one value of P_o because P_m is with small error ($\sim$1%) proportional to P_o over the range of $o.1 \leqslant P_o \leqslant 1o$ torr and the range of velocities plotted.

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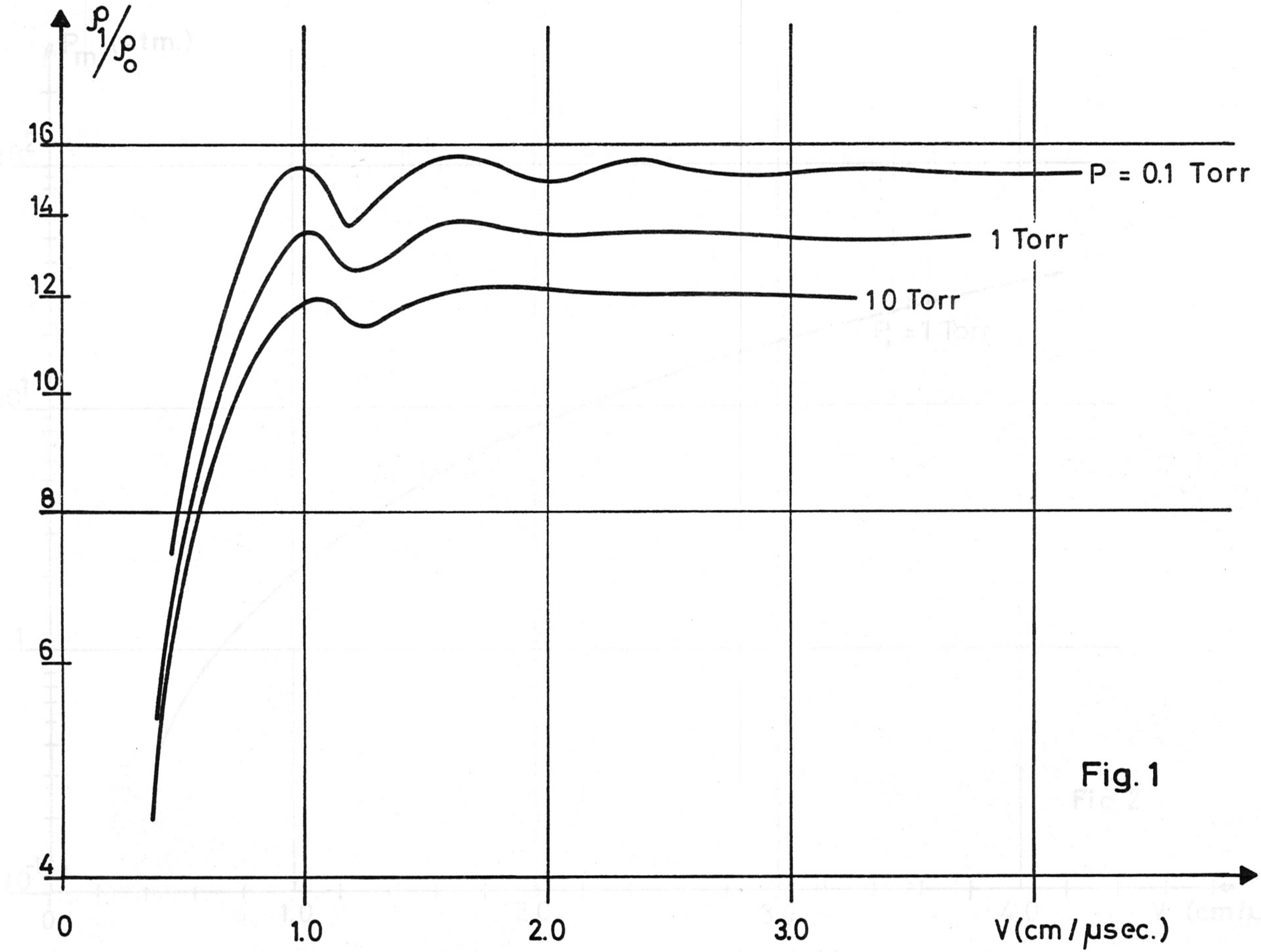


Fig. 1

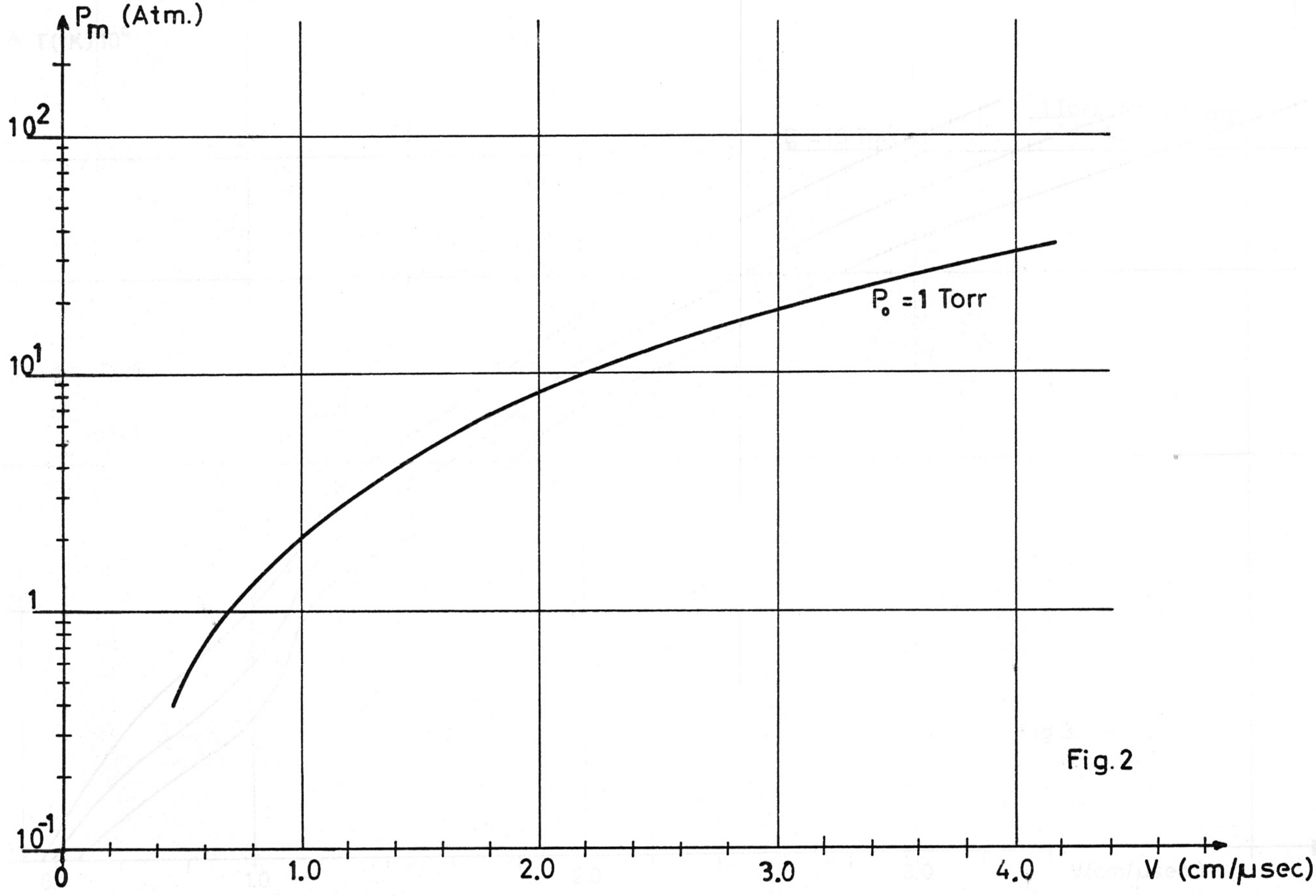


Fig. 2

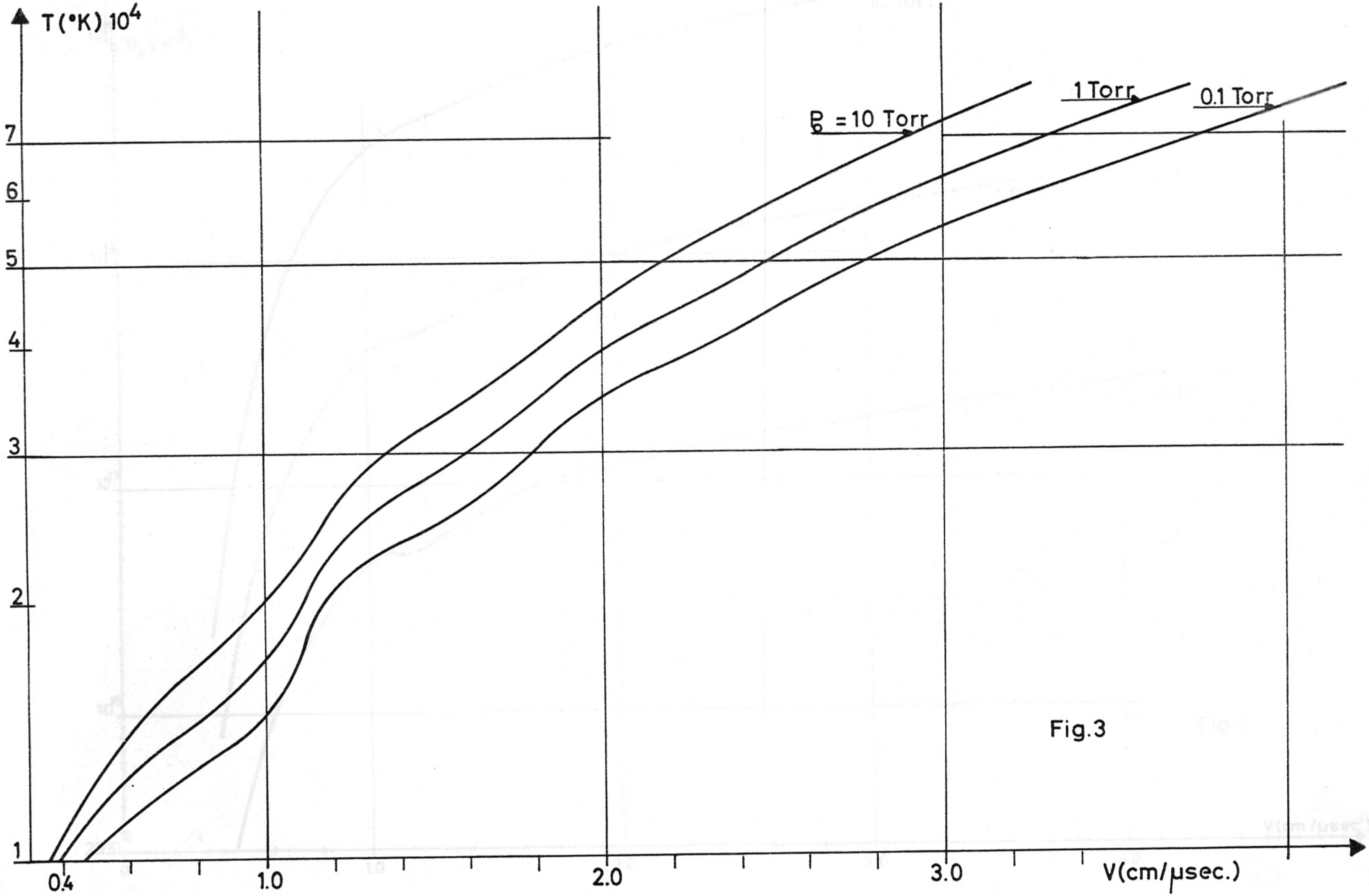
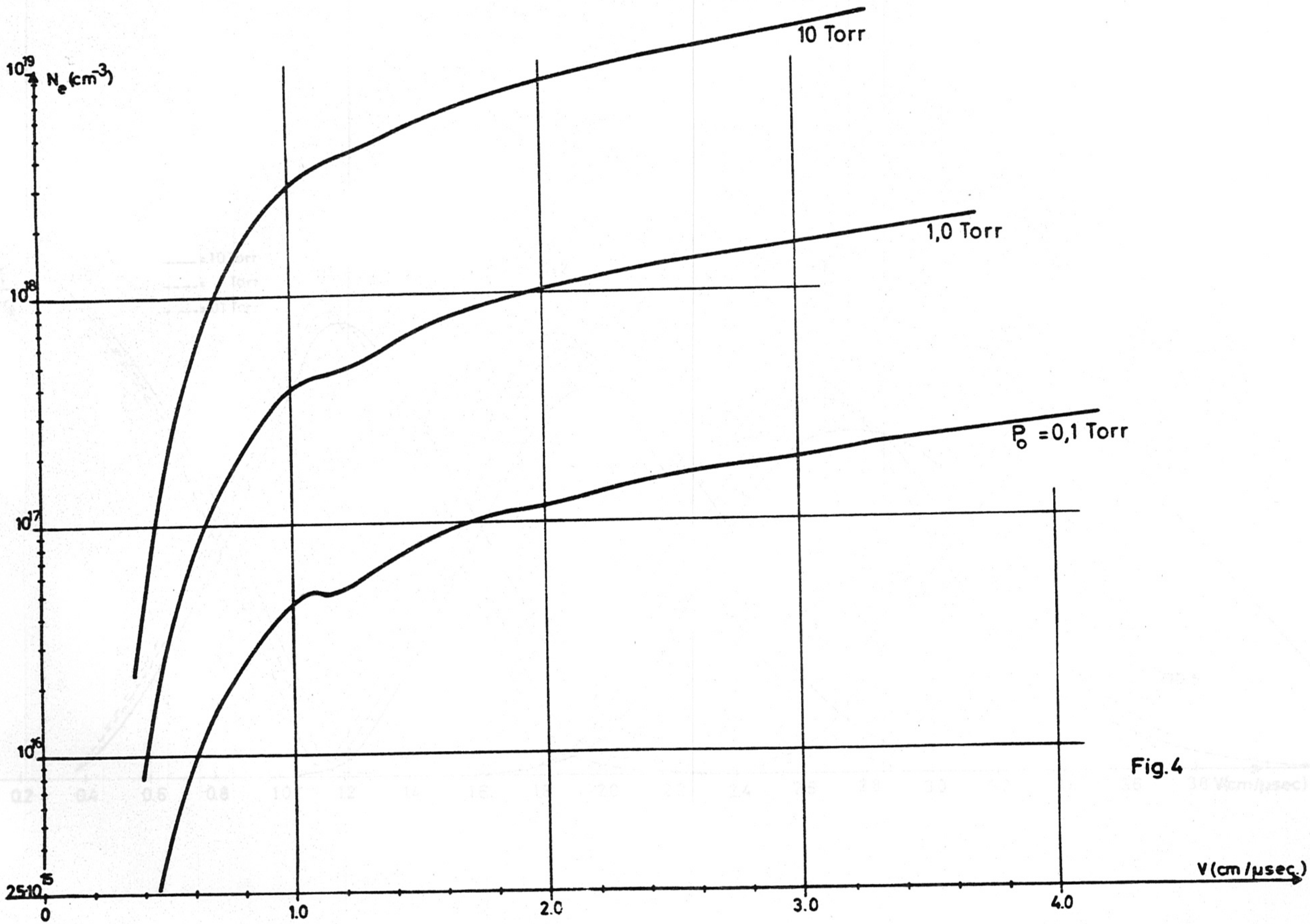
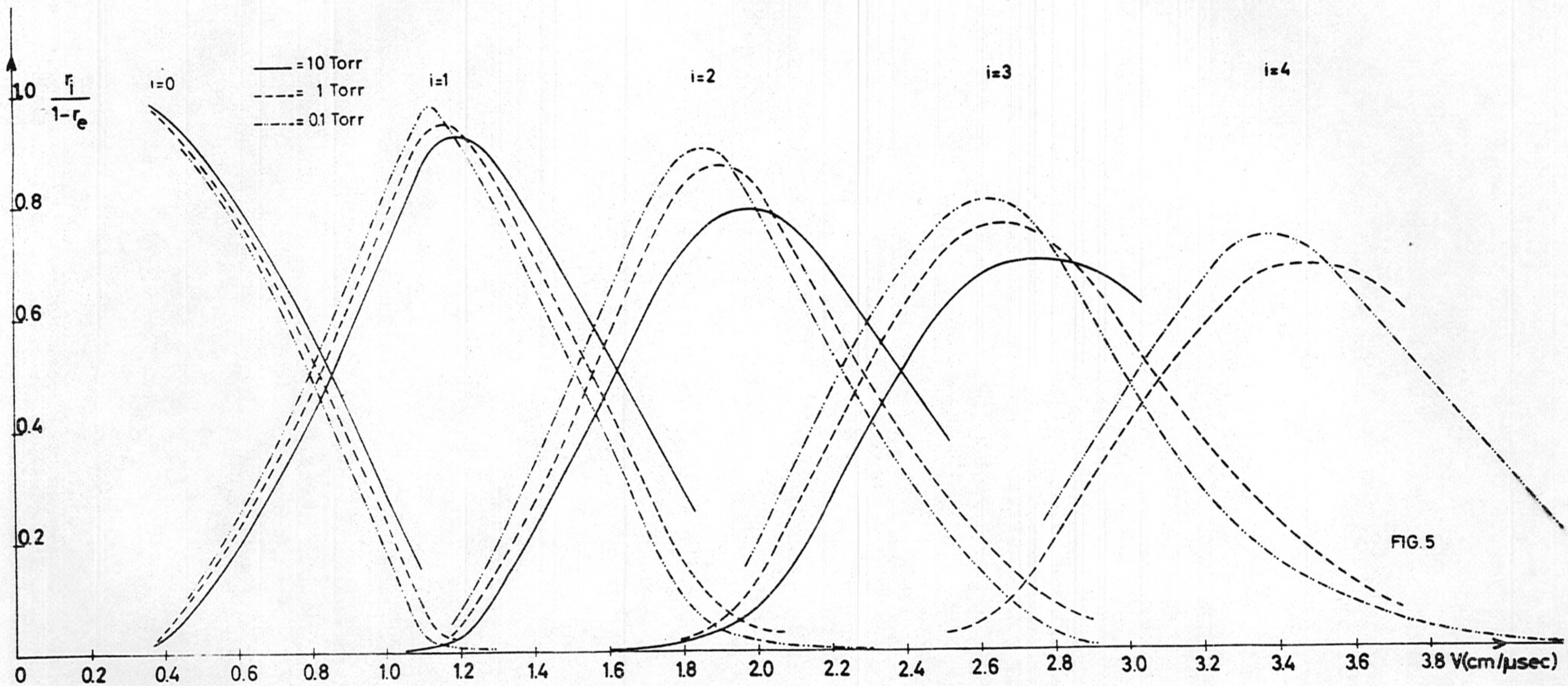


Fig.3



10^{19} $N_e (cm^{-3})$
10^{18}
10^{17}
10^{16}
$2.5 \cdot 10^{15}$
0
1.0
2.0
3.0
4.0
V(cm/µsec.)
10 Torr
1,0 Torr
P_o =0,1 Torr

Fig. 4



1.0
0.8
0.6
0.4
0.2
$\frac{r_i}{1-r_e}$
i=0
i=1
i=2
i=3
i=4
= 10 Torr
= 1 Torr
= 0.1 Torr
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8 V(cm/µsec)

FIG. 5