daß in diesen Bereichen die einfache Form der Maxwell-Wagnerschen Theorie in guter Näherung direkt anwendbar ist. Man kann in diesem Bereich die aus den Maxwell-Wagnerschen Formeln folgenden Ergebnisse mit den Resultaten aus empirisch gewonnenen Näherungsformeln vergleichen, die sich in diesem Frequenzbereich bewährt haben [9], und zwar einer Formel für ε' von BÖTTCHER [10] und einer daraus abgeleiteten Formel für ε'' von BARRER und SAXON-NAPIER [7]:

$$\frac{\varepsilon'-1}{3\,\varepsilon'} = \eth \cdot \frac{\varepsilon_2'-1}{\varepsilon_2'+2\,\varepsilon'}\,,$$

$$\varepsilon'' = \frac{(3\,\eth-1)\,(\varepsilon')^2+(3\,\eth-1)\cdot 2\,\varepsilon'+1}{(3\,\eth-1)\cdot 2\,(\varepsilon')^2+(3\,\eth-2)+4\,\varepsilon'}\,\varepsilon_2''.$$

Zur Durchführung dieses Vergleiches wurden Messungen an Zinkoxidpulver bei einer Frequenz von $9{,}5\cdot 10^9$ Hz mit einer 3 cm-Mikrowellenapparatur und bei $4\cdot 10^{10}$ Hz mit einer 8 mm-Mikrowellenapparatur ausgeführt.

Gemessen wurde (es wird statt $\operatorname{tg}\delta$ der daraus berechnete Wert für die Leitfähigkeit angegeben):

$$\varepsilon' = 1{,}28 \pm 0{,}05\,; \quad \sigma = (1{,}3 \pm 0{,}2)\cdot 10^{-4}\ [\Omega^{-1}\,\mathrm{cm}^{-1}].$$

Diese Meßwerte wurden übereinstimmend für beide Meßfrequenzen erhalten, im Einklang mit den Aussagen der Maxwell-Wagnerschen Theorie für diesen Frequenzbereich (Abb. 1).

Daraus wurde für den homogenen Halbleiter berechnet

a) aus den empirischen Formeln:

$$\varepsilon_2' = 6{,}5 \pm 0{,}3\,; \quad \sigma_2 = (6 \pm 1)\cdot 10^{-3}\ [\Omega^{-1}\,\mathrm{cm}^{-1}],$$

b) aus den Maxwell-Wagnerschen Gleichungen:

$$\varepsilon_2' = 6{,}5 \pm 0{,}3\,; \quad \sigma_2 = (4 \pm 1)\cdot 10^{-3}\ [\Omega^{-1}\,\mathrm{cm}^{-1}].$$

Sucht man nach den Ursachen der Anwendbarkeit der Maxwell-Wagnerschen Gleichungen gerade bei diesen hohen Frequenzen, so liegt der Schluß nahe, daß in diesem Frequenzbereich, in dem die Meßergebnisse für ε' und σ unabhängig von der Meßfrequenz sind (Abb. 1), die Übergangswiderstände zwischen den Körnern des Pulvers kapazitiv kurzgeschlossen werden und damit die oben erwähnten Unterschiede der gegenseitigen Orientierung und Berührung der Körner keine Rolle mehr spielen, womit die wichtigste Ursache für das Versagen der einfachen Maxwell-Wagnerschen Theorie entfiele.

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Measurements of the Electron Drift Velocity in Helium Gas at High Pressure

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Measurements at pressures above 1 at have shown that for constant E/p (E = electrical field strength, p = pressure) the drift velocities of electrons decrease with increasing pressure [1–6]. Until now this "pressure effect" was found only in the molecular gases H_2 [1, 2], N_2 [1–3], D_2 [4], ethane, propane [5] and CO_2 [6]. It is characteristic that it occurs within or slightly above the E/p-range in which the electrons are in thermal equilibrium with the surrounding gas. In this paper a similar effect for the monoatomic helium gas is described. Earlier measurements at room temperature [2] up to 40 at were extended from $E/p = 0.01$ V/Torr cm down to 0.003. An increasing deviation of v_-, well out of the limits of error, was obtained over this E/p-range.

Near the normal boiling point of 4.19 °K LEVINE and SANDERS [7] found in helium gas a strong p-dependence of v_- and proposed an explanation.

The experimental method (time of flight method) has been described in [1, 2]. The uncertainty in E/p is below 0.5% given by a possible error of 0.4% in the voltage and a possible error of 1‰ in the pressure measurement (high pressure metallic bourdon tube capsule, Texas Instruments Inc.). The voltage oscillogram rises linearly between 0 and T_- (drift time of the electrons) and bends at a sharp angle to a horizontal line at these times (see Fig. 1 in [1]). In this case the error for T_- is 1%. For lower E/p and higher pressures the error increases up to 5% due to a distortion of the linear rise (see below). The purity of the helium was 99.999%. The vacuum of the high pressure vessel before filling ($1\cdot 10^{-3}$ Torr) guarantees this purity of the gas for pressures above 1 at for several days. In Table 1 the equivalent ideal gas pressures are given taking into account deviations from the ideal gas law.

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E/p V/Torr cm	32 600 Torr	23 960 Torr	17 400 Torr	8450 Torr	2915 Torr	values from [8]
0,003	2,03 ± 5%	2,08 ± 2%	2,12 ± 2%	2,19 ± 1%	2,21 ± 1%	—
0,004	2,66 ± 3%	2,74 ± 2%	2,78 ± 2%	2,91 ± 1%	2,91 ± 1%	—
0,005	3,32 ± 2%	3,37 ± 2%	3,43 ± 1%	3,57 ± 1%	3,59 ± 1%	—
0,006	3,89 ± 2%	3,95 ± 2%	4,06 ± 1%	4,17 ± 1%	4,19 ± 1%	4,18
0,008	5,06 ± 1%	5,15 ± 1%	5,27 ± 1%	5,38 ± 1%	5,38 ± 1%	5,33
0,01	6,20 ± 1%	6,24 ± 1%	6,30 ± 1%	6,44 ± 1%	6,42 ± 1%	6,37
0,015	8,60 ± 1%	8,65 ± 1%	8,66 ± 1%	8,68 ± 1%	8,68 ± 1%	8,63
0,02	10,5 ± 1%	10,55 ± 1%	10,62 ± 1%	10,60 ± 1%	10,60 ± 1%	10,52

Table 1. Measured electron drift velocities $v_- \cdot 10^{-4}$ [cm/sec] in helium, normalized to 20 °C.

Experimental Results

Figure 1 shows the relationship between v_- and E/p and Fig. 2 the reduction of $v_-(p)/v_-$ (2915 Torr) with increasing pressure calculated from Table 1. The full lines in Fig. 2 were obtained as ratios of the averaged curves in Fig. 1. In Fig. 1 the curves for 8450, 17 400 and 23 960 Torr have been omitted.

In both cases (dots and full lines) the deviation of v_- with increasing pressure exceeds the limits of error, which increase also with increasing pressure. The p-dependence is evident only above 8000 Torr and according to the curves in Fig. 2 seems to become constant for E/p below 0.006.

It was found by the method described in [9] that the distortion of the linear rise mentioned above is caused by a reduction of the released number of electrons n_0 during T_-. The oscillograms show a decreasing slope in this case. This has been investigated more accurately with the following result: The number of released electrons n_0 is reduced according to the law

$$n(t) = n_0 \, e^{-t/\tau_a}$$

(τ_a = life time of the free electrons).

At the same time slowly drifting particles are formed, which have nearly the same velocity as negative O_2^--molecules in O_2. Because $1/\tau_a$ is not proportional to p^2 these particles cannot be O_2^-. Also negative molecules of H_2O can be excluded. The source of these particles (smallest impurity or helium itself) is still uncertain.

Discussion of the Results

According to the full lines in Fig. 2 the decrease of v_- is nearly proportional to p. The experiments in H_2, N_2 ethane and propane had the same result in a more distinct way. A resonance like delay caused by rotational or vibrational resonance states [5, 10] cannot be taken as an explanation for the pressure effect in helium, because such states are not possible for the helium atom. LEVINE and SANDERS [7] measured the strong p-dependence of v_- only for low temperature helium. They explain their results by assuming that the electrons drift in correlated ("bubble") states of the helium atoms through the gas. It is open whether these states are of influence at room temperature. Possibly another explanation is necessary for the p-dependence of v_- reported here.

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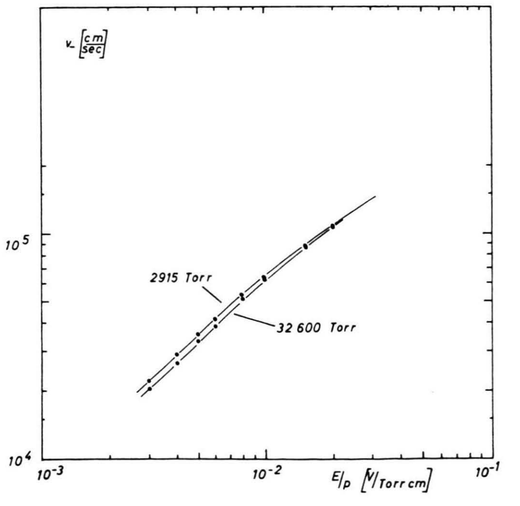

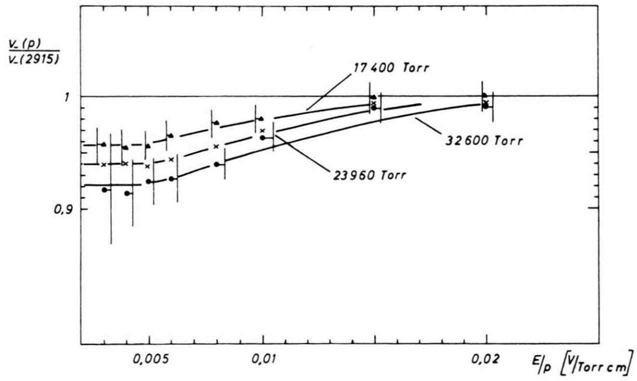

Fig. 2. Decrease of $v_-(p)/v_-$ (2915 Torr) with increasing pressure.

← Fig. 1. Drift velocity v_- as function of E/p for the pressures 2915 and 32 600 Torr.

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