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ELECTRON MOBILITY IN HIGH DENSITY NEON GAS

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The electron - atom scattering cross section in Ne is much smaller than that of other simple gases. Therefore the electron mobility is field-dependent even for very low fields. The zero-field electron mobility can be determined by extrapolation from $\mu(E)$ curves only.

Introduction

The density and temperature dependence of the electron drift mobility in high density Ne gas has been recently measured [1,2] using a "square wave" technique /SWT/. (Fig.1). This technique has been extensively described elsewhere [3].

For the current of the sample cell we get i=0 for $f \gg f_e$ and $i=(I_o/2)(1-f/f_e)$ for $f \ll f_e$. f_e and f are the constant and the variable square wave frequencies between G1-G and G2-C. I_o is the current measured at zero frequency. The electron time of flight between G2 and C, $\tau_e=(2f_e)^{-1}$, is given by linear extrapolation to i=0. The mobility is then obtained as $\mu = d/(\tau_e E)$ /E is the electric field/.

When electron attachment to molecular impurities /usually oxygen/ is present, the same relation i(f) holds, but I_o is now replaced by $I_o\exp(-\omega/f_e)$, where ω is the attachment frequency. An impurity concentration of 0.01 ppm can be detected with this method.

Measuring of the electron mobility

The SWT technique has been used to measure the electron mobility at very low values of the reduced field E/N, where N is the gas number density /typical values are $E/N \approx 10^{-25} m^2 V$./At such low E/N values the electrons are thermalized in the He, H_2, Ar, N_2, Kr, Xe, but not in Ne, where the electron-atom scattering cross section is very small.

In Ne, therefore, the electron mobility is field-dependent and the "zero-field" mobility μ_o can only be extrapolated from the $\mu(E)$ curves /Fig.2/.

In low density gases the classical theory gives a formula for μ_o as a function of temperature T, density N, and the thermal scattering cross section σ_{TH}

$$\mu_0 = \frac{4e}{3N\sigma_{TH}(2mk_BT)^{1/2}}, \tag{1}$$

$$\sigma_{TH}^{-1} = (k_BT)^{-2}\int_0^\infty d\epsilon \frac{\epsilon \exp(-\epsilon/k_BT)}{\sigma_{mt}(\epsilon)}, \tag{2}$$

where σ_{mt} is the energy-dependent momentum transfer cross section.

In the low density limit $\mu_o N$ should be density-independent $\lim_{N\to 0}(\mu_o N) = (\mu_o N)_o = A(T)$. The function A(T), calculated from /1/ and /2/ for Ne is plotted in Fig.3. The agreement with the extrapolated $(\mu_o N)_o$ data /closed circles/ is substantially good.

<u>Multiple scattering effects</u>

The classical theory, however, fails at finite density and several theories have been proposed [4,5,6] to explain the experimental data, which account for multiple scattering effects. All these theories /MST/ suggest, at moderate densities, a linear decrease of $(\mu_o N)$ with N for gases with a positive scattering length,a, like He,H_2 and Ne:

$$\mu_0 N = (\mu_0 N)_0 (1 - \gamma N) = A(T) - \alpha N, \tag{3}$$

where $\gamma = h \cdot \sigma_{TH}/\ 2(2\pi m k_B T)^{1/2}$, and $\alpha = eh/(3\pi m k_B T)$.

The mobility behaviour predicted by /3/ is qualitatively /and for He and H_2 also quantitatively/ in agreement with the experimental results. For Ne a density dependence of $\mu_o N$ much stronger than the expected one has been measured.

The $\alpha \cdot T$ vs. T functions for different gases are shown in Fig.4. The constant theoretical value $\alpha = eh/(3\pi m k_B T)$ is drawn by dashed line. α is derived from the experimental slope of $\mu_o N$ vs. N.

<u>Thomson discharge method</u>

In order to check the strange results for Ne we repeated our measurements with the "Thomson discharge method" [9]. The TDM has been adapted to our low temperature and high pressure drift cell.

A pulsed photocathode has been used as electron source, and the electron time of flight has been measured by means of fast electronics and a transient recorder.

Special care has been also devoted to avoid systematic errors due to the finite electrodes geometry and to the electron attachment.

The "zero density" values $(\mu_o N)_o$ obtained with TDM /open circles in Fig.3./ are now in perfect agreement with MST.

At high density,the density dependence of $\mu_o N$ is still much stronger than predicted by MST /Fig.4, open circles/, leading us to the conclusion that the multiple scattering theories by alone are inadequate to explain the electron mobility behavior in high density Ne.

An important peculiarity of Ne, with respect to other gases with $\alpha > 0$, is that $\sigma_{mt}(0)$ is much smaller, and moreover $\sigma_{mt}(\varepsilon)$ is strongly dependent on the electron energy ε/a comparison with He and H_2 is shown in Fig.5/.

Conclusions

Starting from this consideration we suggest a rough model to fit the experimental results. Essentially we assume that the effective cross section is affected by density through the Fermi shift [10] of the electron ground state energy ε_o.

Such an effect, in fact, becomes important in Ne owing to the steepness of the $\sigma_{mt}(\varepsilon)$ curve at low energy /it is negligible in He and in H_2 where $\sigma_{mt}(\varepsilon)$ is flatter/.

In Fig.6 the data obtained at three different temperatures are plotted as $\mu_o N$ versus N. The full line is calculated following MST and the dashed line is calculated following our model without any adjustable parameters. Inspite of the crudeness of our approach the agreement is good, suggesting that more theoretical effort in this direction could offer a correct interpretation of the electron mobility in dense gases.

References

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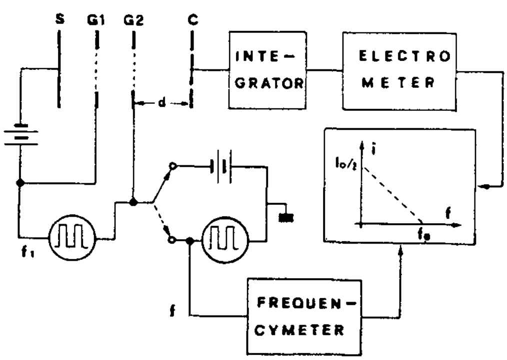

Fig.1. The square wave technique [1,2]

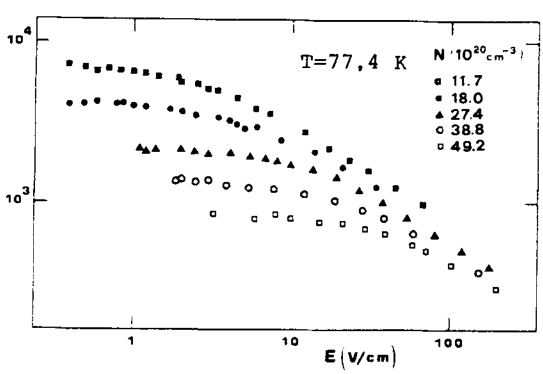

Fig.2. Electron mobility in Ne vs. electric field

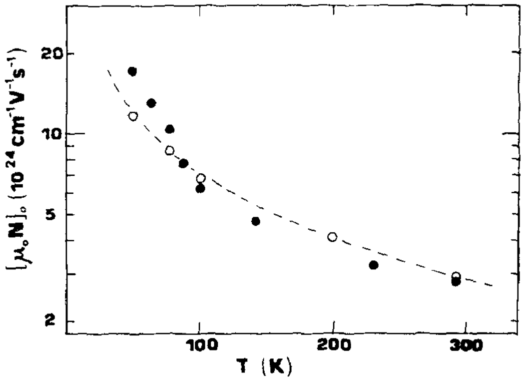

Fig.3. $\mu_0 N$ extrapolated to zero density vs. temperature

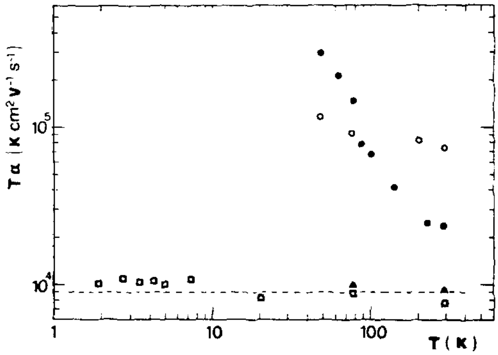

Fig.4. αT vs. temperature

- □ He [7,8]
- ▲ H_2 [8]
- ○ Ne /SWT/
- ● Ne /TMD/ [1,2,9]

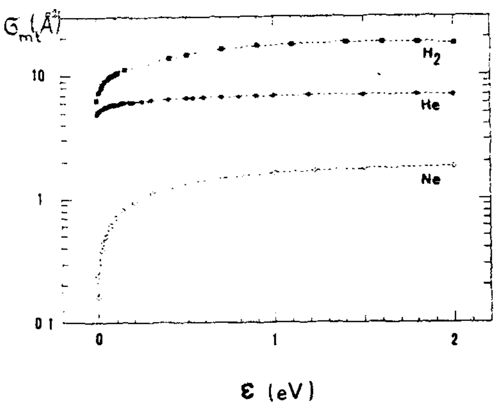

Fig.5. Momentum transfer cross section of low energy electrons in Ne, He and H_2

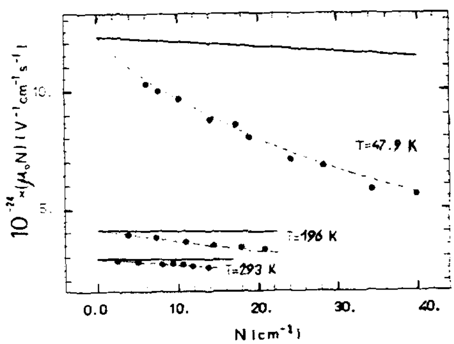

Fig.6. Zero field mobility μ_0 times N in Ne vs. density at different temperatures