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Electron drift velocities in helium-fluorine gas mixtures[a)]

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Using a simple time-of-flight technique, we have measured the electron drift velocity in helium with 0.1–1% fluorine additive. Our results in a 0.1% mixture are in close agreement with data in pure helium. The measured drift velocity increases with increasing fluorine concentration.

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Modeling of HF [1] and rare gas–halide lasers[2–4] requires accurate data on electron transport coefficients in gas mixtures containing fluorine. We are presently engaged in a general program for direct experimental determination of these parameters, and have previously measured the rate coefficient for electron dissociative attachment[5] in low concentrations (0.1–1.0%) of F_2 in He. The objective of this letter is to report measurements of the electron drift velocity v_d under similar experimental conditions.

In general, the electron drift velocity is related to the velocity distribution $f_0(v)$ by the relation

$$v_d = -\frac{4\pi}{3}\frac{e}{m}\frac{E}{N}\int_0^\infty \frac{v^2}{q_m(v)}\frac{df_0(v)}{dv}\,dv\,, \tag{1}$$

where conventional gaseous electronics notation has been used. Note that $f_0(v)$ is normalized according to

$$4\pi\int_0^\infty v^2 f_0(v)\,dv = 1$$

and is defined in such a way that it represents the distribution function for a steady stream of electrons at a given E/N, but with allowance for inelastic collisions. A direct measurement of the electron drift velocity can therefore be used to estimate the mean energy if the effective cross section for momentum transfer, $q_m(v)$, is known.

The principle of our method is to produce a short and well-localized pulse of photoelectrons at time $t=0$ and observe their motion between two plane-parallel electrodes. The number density, $n(\mathbf{r}, t)$, within the resulting traveling group of electrons, taking both elastic and inelastic collisions into account, is governed by[6]

$$-\frac{\partial n}{\partial t} + (\bar{\nu}_i - \bar{\nu}_a)n + D_\perp\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)n + D_\parallel\frac{\partial^2 n}{\partial z^2} - v_d\frac{\partial n}{\partial z} = 0 \tag{2}$$

In Eq. (2), $\bar{\nu}_i$ and $\bar{\nu}_a$ are the average ionization and the attachment frequencies, respectively, Furthermore, $D_\perp$ and $D_\parallel$ represent the diffusion coefficients perpendicular and parallel to the z direction. The distance traveled by the centroid of the diffusing electron group over a time t is given by

$$\bar{z} = v_d t\,. \tag{3}$$

Assuming that an initial number of electrons $n_0(0)$ starts drifting from the cathode ($z=0$) at time $t=0$, the solution to Eq. (2) may be written as

$$n(\mathbf{r}, t) = \frac{n_0(0)\exp[(\alpha-\eta)\bar{z}]}{(4\pi D_\perp \bar{z}/v_d)(4\pi D_\parallel \bar{z}/v_d)^{1/2}}\exp\left(-\frac{(x^2+y^2)v_d}{4D_\perp\bar{z}}\right)$$
$$\times\exp\left(-\frac{(z-\bar{z})^2 v_d}{4D_\parallel\bar{z}}\right), \tag{4}$$

where α is a Townsend's first ionization coefficient and η is the attachment coefficient. We note from Eq. (4) that, to the order of approximation to which it is valid to use Eq. (2), the position of the electron centroid has not been modified by the presence of weak ionization and/or attachment, and we are therefore justified in employing a time-of-flight method to determine the electron drift velocity.

The details of the apparatus have been described elsewhere.[5] With light from a pulsed Xe-ion laser[7] we generate $n_0(0)$ photoelectrons at the cathode at time $t=0$. Mathematically, $n_0(0)$ has been corrected for back-diffusion to the cathode and represents the number of electrons that start drifting through the gas against the electric field E. If there were no electron loss or gain processes, we would measure a *constant* current in the external circuit during the electron transit time T_-. In order to increase the sensitivity of the method we *integrate* the current pulse and then observe a linearly rising voltage pulse at the output of the amplifier in Fig. 1. In the presence of attachment, the integrated electron current rises as $[1-\exp(-\eta v_d t)]$. It exhibits a discontinuity at $t=T_-$ since $v_d \gg v_n$ (negative ion drift velocity), allowing the electron drift velocity to be determined from $v_d = d/T_-$. (d is the electrode separation, which may be changed from 0.3 to 3 cm.)

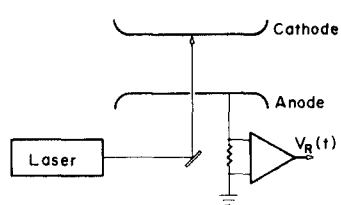

FIG. 1. Principle of experiment. Light from a Xe-ion laser (2315 Å; 100 nsec half-width) passes through a 1-mm aperture in the anode and produces photoelectrons within a 0.2-diam spot on the cathode. The resultant electron current transient is integrated and displayed on an oscilloscope.

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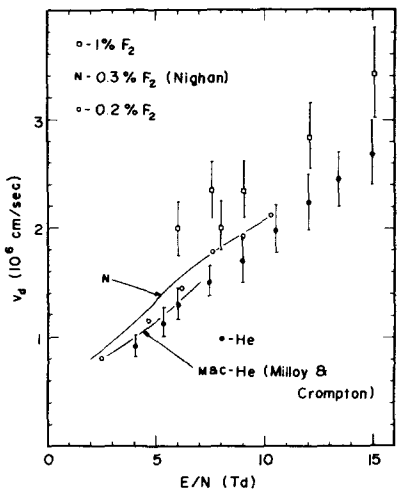

FIG. 2. Electron drift velocities in He-F_2 mixtures as a function of E/N. All data points are present results. The full-drawn curve marked N is due to Nighan (Ref. 9) and pertains to a calculation in 0.3% F_2 + 99.7% He. The curve marked M& C depicts measurements in pure helium by Milloy and Crompton (Ref. 8).

First, to check out the method, we have measured the electron drift velocity in pure helium (Fig. 2) and compared our results with those of Milloy and Crompton.[8] In the overlapping E/N region, there is agreement within the experimental errors. (Milloy and Crompton claim an accuracy of better than ±1.5%; the present accuracy is ±10%.)

Second, in a gas mixture consisting of 1% F_2 + 99% He, there is a definite increase in the drift velocity, as shown by the open squares. (It was practically impossible to get any data at higher fluorine concentrations for the reason that most of the electrons would be lost due to attachment taking place close to the cathode.) At a lower fluorine concentration (0.2%), there is a discernable difference in the measured v_d values as compared to our own results in pure He. At a concentration of 0.1% the observed v_d values fall within 10% of the pure He data. (Our experimental errors in v_d are increased to 12–15% when F_2 is admitted to the system.)

The systematic trend showing an increase in electron drift velocity with increasing fluorine concentration has been supported by Nighan[9] in a recent calculation for a 0.3% F_2 + 99.7% He mixture (see curve marked N in Fig. 2). His model includes vibrational excitation, dissociative attachment, and dissociation of the F_2 molecule, and the results are consistent with the experimental data.

The increase in drift velocity that results from the addition of F_2 is similar to that which has been observed previously when a molecular gas has been added to,[10,11] or has been present in,[12,13] a monatomic gas. The increased mobility is due to the introduction of numerous low-energy inelastic energy exchange processes that are absent in a pure monatomic gas. The enhanced energy exchange between the electron swarm and the gas reduces the average energy of the electrons in the swarm and hence increases the mobility.

In the case of fluorine, there is an additional process which acts to *decrease* the mobility. Since the attachment rate for dissociative attachment in F_2 decreases with increasing electron energy,[5,14] the low-energy fraction of the swarm tends to be depleted preferentially. The remaining electrons will thus have a mean energy that is higher than would otherwise be the case with a consequent reduction in their mobility. We are unable to assess the significance of this latter process, which might be termed *attachment heating*, due to the lack of cross-section data, but it is evident that it is less significant than the former process.

Our observations confirm that, in rare gas–fluorine lasers, the electron velocity distribution, and consequently the electron drift velocity, is strongly dependent on fluorine concentration. However, for a fluorine concentration of 0.1% our measurements show no detectable effect on the electron drift velocity, thus supporting recent model calculations.[2–4,9]

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