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KINETIC-ENERGY DISTRIBUTIONS OF K^+ IN ARGON AND NEON IN UNIFORM ELECTRIC FIELDS

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Introduction

In many instances the mobility and diffusion coefficients of an ion in a gas are insufficient parameters for the modeling of a discharge because of the importance of the ions composing the high-energy portion of the kinetic-energy distribution. A knowledge of the kinetic-energy distributions for ions in a background gas as a function of electric field-to-gas density ratio (E/N) is necessary for the understanding of ion-molecule interactions in many applications, such as material etching by low-temperature plasmas. Experimental investigations of the kinetic-energy distributions of ions under well-defined, drift-tube conditions are rare.[1-4] In this work, we have measured the kinetic-energy distributions of potassium ions accelerated by a uniform electric field in argon and neon buffer gases.

Experiment

A schematic diagram of the experimental apparatus consisting of a uniform-field drift tube and an ion energy analyzer-mass spectrometer system, is shown in Fig. 1. Potassium ions are produced by a thermionic source and are accelerated down the drift tube by the electric field formed by the voltages applied to the rings. The drift tube is 22.5 cm long and has an inner diameter of 8.2 cm. The buffer-gas pressure in the drift tube was 13.3 Pa (100 mTorr) for the data presented here, with a flow rate of 6×10^{-3} Pa m^3/s (3 sccm). The uncertainty in the determination of the E/N is less than $\pm2\%$, due primarily to uncertainties in the pressure and length measurements. The ion current is measured at the end plate of the drift tube by an electrometer and did not exceed 0.1 μA for any conditions used here.

Ions are sampled through a 200 μm hole in the center of the end plate of the drift tube, and enter the differentially pumped region of the ion energy analyzer-mass spectrometer. The ion energy analyzer-mass spectrometer system is the same as used previously to investigate the kinetic-energy distributions of ions sampled from low-pressure, radio-frequency discharges and has been described in detail elsewhere.[5] Ion kinetic-energy distributions are measured by setting the quadrupole mass spectrometer to a particular mass-to-charge ratio, and then scanning the ion energy allowed through the cylindrical mirror ion-energy analyzer (CMA). The acceptance angle and the energy resolution of the ion-energy analyzer are 3° and 1 eV, respectively, and the uncertainty in the energy scale is approximately ±1 eV.

Results and Discussion

Kinetic-energy distributions for K^+ drifting in argon and neon buffer gases are presented in Fig. 2 for several E/N ranging from 120×10^{-21} to 450×10^{-21} Vm^2

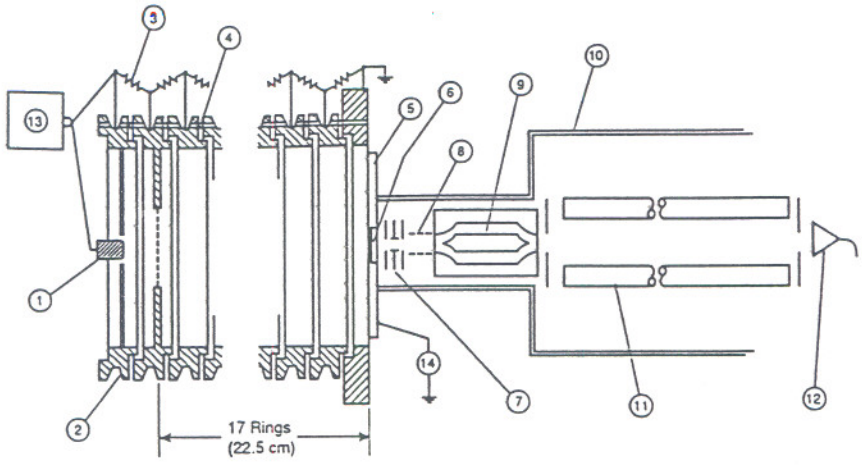

Figure 1. Schematic diagram of the drift tube and mass spectrometer with ion-energy analyzer: 1) thermionic K^+ source; 2) drift tube ring; 3) 1 MΩ vacuum resistor (1%): 4) insulating ruby ball spacer; 5) end plate; 6) 200 μm sampling orifice; 7) ion transfer optics; 8) electron-impact source (not used in these studies); 9) cylindrical mirror analyzer (CMA); 10) mass spectrometer vacuum housing; 11) quadrupole mass spectrometer rods; 12) electron multiplier detector; 13) high-voltage power supply; 14) electrometer.

(1×10^{-21} Vm^2 = 1 Td). Between 4 and 10 energy scans were taken at each E/N and then averaged. The data in Fig. 2 have been normalized to the maximum of each distribution. The mean energies, $\langle\varepsilon\rangle$, of the distributions are also shown. As expected, the distributions are approximately Maxwellian in shape, with the mean energy increasing with increasing E/N. The distributions for K^+ in neon exhibit higher mean energies and have higher energy tails than the distributions in argon. This is due to the lower mass of neon, resulting in less energy loss by momentum-transfer collision which, in this E/N range, is expected to be the primary energy-loss mechanism.

The source of the minor structure observed in the distributions for neon buffer gas at higher E/N is unknown at this time. The possibility of instrumental effects are being investigated, as is the possibility that at high E/N in a low-mass buffer gas the ion motion exhibits deviations from the equilibrium condition so that their motion cannot be adequately described in terms of a drift velocity.[6]

The sampling procedure through the orifice is known to discriminate against lower energy ions, and therefore the low-energy end of the distributions may not accurately represent the ion energies inside the drift tube. This discrimination will tend to overestimate the mean energy of the ions when compared to the average ion energy calculated from reduced mobility data.[7] This has been observed to be the case, with the measured mean energies presented here consistently exceeding those calculated using the average drift velocities.

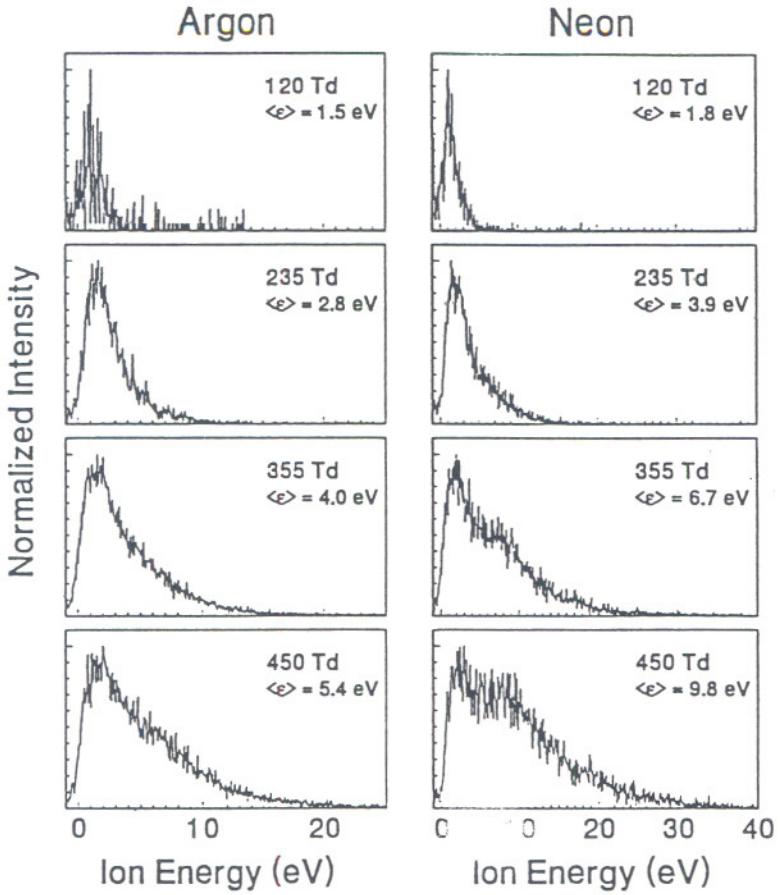

Figure 2. Kinetic-energy distributions of K^+ in argon and neon buffer gases at the indicated E/N (1 Td $\equiv 1 \times 10^{-21}$ Vm^2). The mean energy, $\langle\varepsilon\rangle$, of the distribution at each E/N is also indicated.

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