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RAPID COMMUNICATION

Electron transport coefficients in SF_6 and xenon gas mixtures

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Abstract. The electron swarm growth processes in SF_6–Xe gas mixtures have been studied by a pulsed Townsend method over the range $32.24 \leqslant E/N \leqslant 564.2$ Td (1 Td = 10^{-21} Vm^2), where E is the electric field and N is the gas density of the mixture. The variation patterns as a function of the density-reduced electric field of the effective ionization coefficient $\bar{\alpha}$, electron drift velocity Ve and longitudinal diffusion coefficient D_L in SF_6–Xe gas mixtures have been given. The dielectric strength of SF_6–Xe gas mixtures has also been determined, which varies linearly with SF_6 concentration in the gas mixtures.

Some inert gases such as helium, neon, argon, krypton, xenon and mixtures with some gases, such as chlorine and SF_6, are important in practical applications, such as electrical discharge engineering, the development of radiation detectors, gas lasers and plasma technology (Dutton *et al* 1969, Taylon and Leopold 1995).

Since inert gases are monatomic and their atoms are of closed-shell structure, the collision of an electron with an inert gas atom is the most typical case of electron–atom collision processes and has long been investigated in detail by a number of authors (Soulem *et al* 1996). However, the collision processes and transport properties of the mixtures of these inert gases with SF_6 have rarely been studied (Hunter *et al* 1989). The swarm parameter of SF_6–He and SF_6–Ne gas mixtures have been determined by our previous work (Xiao *et al* 1999a, b). The collisional processes and transport properties of the mixtures of other inert gases and SF_6 will be studied here. This communication will study the swarm parameters of SF_6–Xe gas mixtures to help to analyse the effect of Xe as a buffer gas in gas mixtures.

In this study, the effective ionization coefficient $\bar{\alpha}$, the electron drift velocity Ve and the longitudinal diffusion coefficient D_L were determined for SF_6–Xe gas mixtures using a pulsed Townsend method over the range $32.24 \leqslant E/N \leqslant 564.2$ Td (1 Td = 10^{-21} Vm^2), where E is the electric field and N the gas density of the mixture. The apparatus and experimental procedure used in this work were improved from what had been described previously (Xiao *et al* 1999a, b). Briefly, the stainless-steel ionization chamber was 30 cm in diameter and 30 cm in height. The voltage of the cathode in chamber was applied by a dc source, the output voltage of which was set between 0 and –50 kV, the maximum ripple was 20 ppm peak-to-peak, and the voltage stability of the source was better than 0.01%. An XeCl laser with a wavelength of 308 nm, a photon energy of 4.04 eV and an output energy of 60 mJ was used to release primary electrons. The laser pulse duration was 5 ns FWHM (full width half maximum). A pair of 90° Rogowski profile copper electrodes whose overall diameter was 150 mm, with a 10 mm gap, were mounted with their common axis vertical. The cathode was embedded with a 20 mm diameter quartz plate with a very thin gold film (20 nm) in the centre, vacuum-evaporated on its surface flush with the cathode for producing initial electrons. Because the photon energy (4.04 eV) of the laser was larger than the work function (3.9 eV) of gold, primary electrons were released when the laser struck the gold film through the quartz plate. A pre-discharging signal was recorded by a 400 MHz digital memory oscilloscope and the digitized discharging waveform transmitted to a computer for data processing with special software. Thus, the parameter curves were drawn. The room temperature during measurements was 20 °C. Before filling with the gas or mixture under investigation, the chamber was evacuated to a gas pressure of 10^{-4} Pa using a diffusion pump backed by a rotary pump. The leak rate was 1.33 Pa per hour at a gas pressure of 66.5 Pa. The gas or mixture pressure was set to be $P < 40$ KPa, as the experiments show that complete electron swarm wave and discharge parameters can be obtained under this condition. The purity of SF_6 and Xe used in this work was 99.8% and 99.99%, respectively.

Figure 1 shows the density-reduced effective ionization coefficient $\bar{\alpha}/N$. The $\bar{\alpha}/N$ of various mixing ratios in SF_6–Xe can be approximated by:

$$\bar{\alpha}/N = \beta[E/N - (E/N)_{\lim}]$$

where $(E/N)_{\lim}$ is the limiting E/N value, and β is the slope of the curve $\bar{\alpha}/N = f(E/N)$. The values of β and $(E/N)_{\lim}$ depend on the component gases and their ratios. The $(E/N)_{\lim}$ of SF_6–Xe reduces with reduction of the SF_6

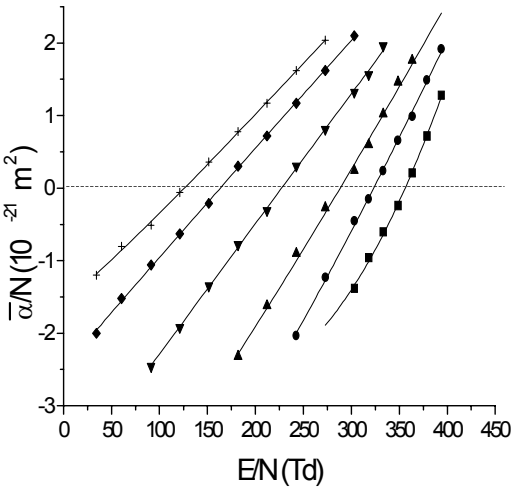

Figure 1. $\bar{\alpha}/N$ as a function E/N measured in SF_6–Xe mixtures of different mixing radios: +, 10/90; ♦, 25/75; ▼, 50/50; ▲, 75/25; ●, 90/10; ■, 100/0.

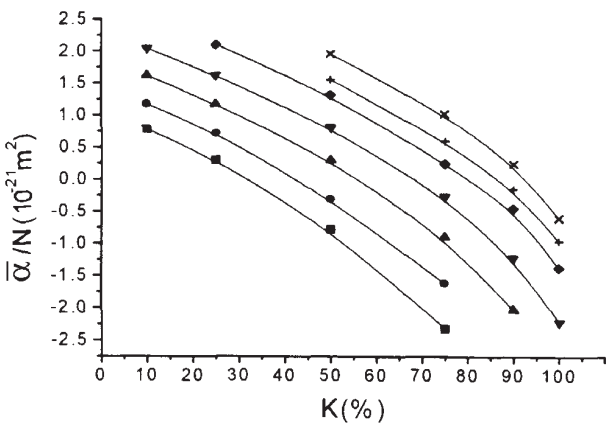

Figure 2. $\bar{\alpha}/N$ in SF_6–Xe mixtures for SF_6 content at constant E/N values (Td): ×, 332.28; +, 317.97; ♦, 303.06; ▼, 272.83; ▲, 242.6; ●, 211.98; ■, 181.75.

component of the gas mixtures; then the electric strength of the gas mixtures reduces too. At the same time, β also decreases with the reduction of the SF_6 component of the gas mixtures. Then, the probability of the transition of a non-self-sustaining discharge into a complete breakdown of the gap in SF_6–Xe mixtures of a certain mixing ratio is reduced.

Figure 2 shows the effective ionization coefficient in SF_6–Xe mixtures for SF_6 content (K) at different E/N values. $\bar{\alpha}/N$ descends with the increase of SF_6 content (K).

Figure 3 shows the relative electric strengths (RES) of the SF_6–Xe gas mixtures compared with that of pure SF_6, and SF_6–He and SF_6–Ne (Xiao *et al* 1999a, b). The RES varies linearly with the fractional concentration of SF_6 (k) in the mixture, similar to that of SF_6–He and SF_6–Ne. Thus, a synergetic effect does not exist in SF_6–Xe gas mixtures. A simple expression can be given to estimate the RES of SF_6–Xe mixtures in the range $0.1 \leqslant k \leqslant 1$

$$\mathrm{RES} = 0.276 + 0.724\ \mathrm{k}.$$

Table 1 shows that the covalent radius and molecular weight of He, Ne and Xe increase and ionization energy

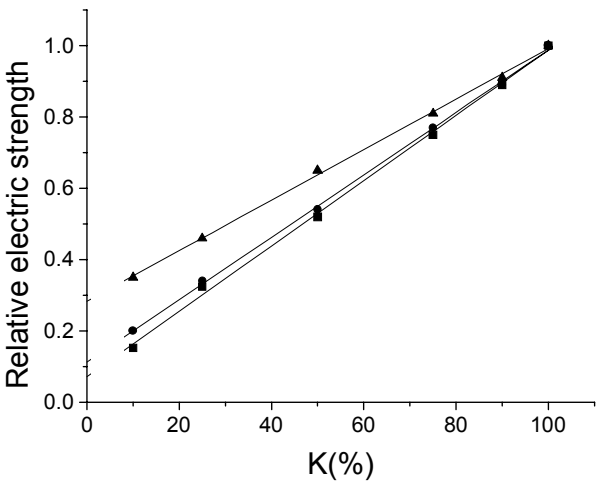

Figure 3. The relative electric strength (RES) of SF_6–Xe, SF_6–He and SF_6–Ne gas mixtures compared with SF_6 content (K): ▲, SF_6–Xe; ●, $SF_6$0-Ne; ■, SF_6–He.

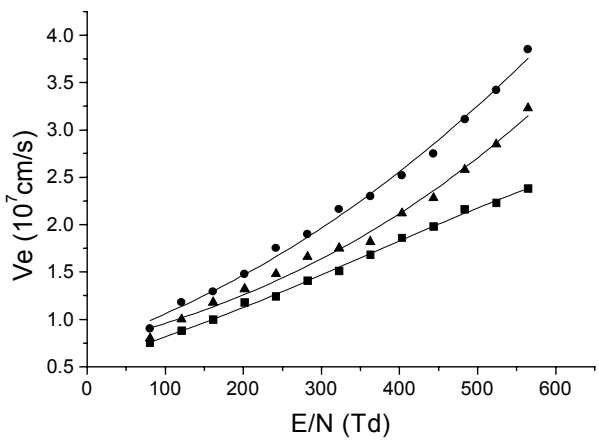

Figure 4. The electron drift velocity as a function of E/N in: ■, SF_6; ▲, SF_6–Xe (50/50); ●, Xe.

Table 1. The ionization energy, covalent radius and molecular weight of inert gases.

Inert gas	He	Ne	Xe
Ionization energy (eV)	24.59	21.56	12.13
Covalent radius (Å)	1.22	1.31	2.18
Molecular weight	4.00	20.17	131.3

decreases sequentially. Using Xe and Ne as an example, although the ionization energy of Xe is lower than that of Ne, when the ionization process begins, the free path of Xe is shorter than that of Ne (because the covalent radius of Xe is longer than that of Ne). Then the acceleration path of Xe is shorter than that of Ne, and thus the accumulation collision energy is lower than that of Ne. On the other hand, the molecular weight of Xe is greater than that of Ne, and thus after the electron collision process with Xe molecules starts, the electron drift velocity decreases more quickly, and the number of high energy electrons reduces further than that of Ne. Thus, the relative electric strengths of Xe are greater than Ne. The relation of Ne and He can also be explained.

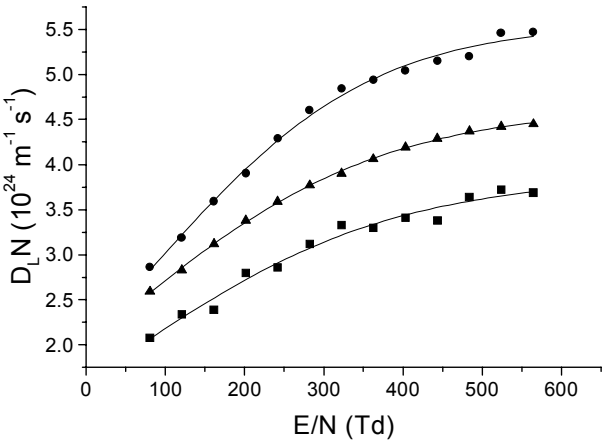

Figure 5. The electron longitudinal diffusion coefficient $D_L N$ as a function of E/N in: ■, SF_6; ▲, SF_6–Xe (50/50); ●, Xe.

The relative electric strengths of the three gases should accord by Xe > Ne > He. Because all the mixture gases used in the test are the linear mixed gases, then after mixing these gases with SF_6, they discharge independently in the discharging process. There is no synergism effect between the inactive gas and SF_6. Thus, the relative electric strengths of the three gases should accord by SF_6–Xe > SF_6–Ne > SF_6–He.

Figure 4 shows the electron drift velocity Ve as a function of the density-reduced electric field in SF_6, Xe and SF_6–Xe (mixing ratio 50/50) respectively. This shows that after Xe is added to SF_6, the Ve in SF_6–Xe increases.

The longitudinal diffusion (D_L) and the transverse diffusion (D_T) exist simultaneously in homogeneous fields. Since, at atmospheric pressure, the velocity distribution of the electrons in the gap is nearly isotropic, the difference between D_T and D_L is negligible, and the diffusion effect of the gas mixtures is expressed by D_L. The electron longitudinal diffusion coefficient $D_L N$ as a function of the density-reduced electric field, in SF_6, Xe and SF_6–Xe (mixing ratio 50/50), is plotted in figure 5. This shows that the diffusion effect of Xe is stronger than that of SF_6, while the diffusion effect of SF_6–Xe (50/50) is between that of SF_6 and Xe. Thus, Xe mixed with SF_6 can change the diffusion effect in pure SF_6.

This work shows that the effect of Xe as a buffer gas in SF_6–Xe gas mixtures is close to that of He and Ne in SF_6–He and SF_6–Ne and can change the transport properties and collision processes.

Acknowledgments

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