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COMPARISON BETWEEN EXPERIMENTAL AND THEORETICAL RESULTS FOR BACK DIFFUSION LOSS OF IONS IN CAVITY IONIZATION CHAMBERS

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Introduction

Some ions produced in a cavity ionization chamber diffuse to the surface of an electrode of the same polarity as their charge, and they therefore do not contribute to the signal current. An equation for the diffusion loss of ions in parallel plate ionization chambers was derived by Langevin(1) some time ago. It has been confirmed experimentally for air at various humidities that the decrease in output current agrees precisely with values obtained from the equations(2).

In previous papers(3,4), we have derived both exact and approximate equations for back diffusion loss of ions in cylindrical and spherical ionization chambers. In this paper, we measure saturation curves for cylindrical ionization chambers to confirm the validity of the equations. After correcting for volume recombination and also for small initial recombination, experimentally obtained diffusion losses are compared with the values obtained from the equations.

Equations for diffusion loss

Exact equations for the diffusion loss of ions in ionization chambers having an ideal parallel plate or cylindrical shape are derived from equations for the flux of ions in electric fields. The equations obtained for the ratio of the decrease in the output current, δI , to the saturation current, I_o , are as follows(3,4),

$$\frac{\delta I}{I_o} = \frac{2kT}{eU} - \frac{2}{e^{eU/kT} - 1} \tag{1}$$

$$\frac{\delta I}{I_o} = 1 - \frac{C\left[2(a^2+b^2)(a^C-b^C) - C(a^2-b^2)(a^C+b^C)\right]}{(2^2-C^2)(a^2-b^2)(a^C-b^C)} \tag{2}$$

for parallel plate and cylindrical chambers, respectively. In these equations, e is the elementary charge, k the Boltzmann constant, U the applied voltage, and T the absolute temperature of the air in the chamber. The symbols a and b are the outer and inner radii of the ion collection volume of the cylindrical ionization chamber. When the voltage U is applied to the inner electrode, the constant C is defined by

$$C = \frac{eU}{kT\ln(a/b)} \tag{3}$$

Approximate equations are obtained from an assumption that ions are lost by back diffusion if they are produced in an electrode vicinity where the electrostatic potential difference from the electrode is less than kT/e. This assumption can be deduced from the following equation which is obtained as an approximation of the exact equation (1) for a parallel plate ionization chamber, assuming that the applied voltage, U, is much larger than kT/e.

$$\frac{\delta I}{I_0} = \frac{2kT}{eU} \tag{4}$$

The approximate equation for $\delta I / I_0$ for a cylindrical ionization chamber is as follows[3,4].

$$\frac{\delta I}{I_0} = 1 - \frac{a^2\left(\frac{b}{a}\right)^{2kT/eU} - b^2\left(\frac{a}{b}\right)^{2kT/eU}}{a^2 - b^2} \tag{5}$$

Experiments

To reduce the effect of volume recombination, it is necessary to use ionization chambers with electrodes separated by small distances and also to use a low γ ray exposure rate. In the present experiment, we constructed four cylindrical ionization chambers having electrodes with outer and inner radii of (4.9, 1.5 mm), (8.0, 2.5), (8.0, 1.5), and (13.1, 2.5). The ratio a/b, between the outer and inner radii of the electrodes for the former two chambers is about 3.2 and for the latter two it is 5.3. The inner (collector) electrodes are surrounded by guard electrodes at both ends to reduce the distortion of the electric field. The length of the ion collection volume is 282 mm for all four chambers. The inner and outer electrodes are made of conductive glassy carbon. The chambers were irradiated with ^{60}Co γ rays; the exposure rate was altered by placing Pb blocks in front of the collimator of the source. The exposure rate was in a range of 9.0-63, 4.7-17, 2.5-9.0, and 1.3-9.0 nC/(kg s), respectively, for the four ionization chambers in this study.

Some experimental data showed discrepancies between absolute currents measured at different polarities of applied voltages. In the present experiment, average values of the absolute currents for both polarities were used for saturation characteristics of the ionization chambers. The temperature of the irradiation room was 21.0-21.3 °C, the pressure 98-102 kPa, and the humidity 22-27 %, throughout all measurements. The fluctuation of these values during one saturation curve measurement was quite small.

Data processing

The main factors for ion loss in ionization chambers include initial recombination, diffusion loss, and volume recombination. When the loss due to these factors is small, the charge collection efficiency f of the signal current can be expressed as

$$f = f_i f_d f_v \tag{6}$$

where f_i, f_d, and f_v are collection efficiencies corresponding to the above factors. Theoretical values of collection efficiency for diffusion loss can be obtained from $f_d = 1 - \delta I / I_0$ using equation (2) or (5) for diffusion loss in cylindrical ionization chambers. Experimental f_d values are obtained from equation (6) with values measured for f. Values for f_i and f_v are obtained as described below.

The following equations of f_v have been proposed for cylindrical ionization chambers by Boag[5].

$$f_v = 1/(1+\xi^2/6) \tag{7}$$

$$\xi = m\frac{[(a-b)\kappa]^2 q^{1/2}}{U} \tag{8}$$

$$m = (\alpha / eK_+K_-)^{1/2} \tag{9}$$

$$\kappa = \left[\frac{a/b+1}{a/b-1}\frac{\ln(a/b)}{2}\right]^{1/2} \tag{10}$$

where q is the charge of ions liberated per unit volume per second, α is the recombination coefficient, K_+ and K_- are the mobility of positive and negative ions, respectively. It is known from parallel plate ionization chamber measurements that the value of m depends on the lifetime of ions in the chamber and also on humidity[6]. In the present paper, we have corrected for volume recombination using the above equations, but using values of m which were estimated from data obtained for parallel plate ionization chambers over a wide range of humidity[7]. In the estimation, the average lifetime of ions in the chambers was calculated assuming that $K_+ = K_-$ and that the ion density distribution does not change by recombination.

It is known that initial recombination also depends on humidity[2]. We used values of f_i obtained as average values for electric fields in cylindrical ionization chambers from parallel plate ionization chamber data[7].

Results and discussion

Figure 1 shows values of f_d for cylindrical ionization chambers with electrodes of different radii. The O symbols show results obtained experimentally, solid lines indicate the exact equation (2), and broken lines indicate the approximate equation (5). The dotted-broken lines in the figures show collection efficiencies, f_i for initial recombination, and dotted lines indicate f_v for volume recombination. These values were used to obtain the experimental results of f_d from values of measured f. Although f_v depends on exposure rate, it is not denoted here which value of f_v corresponds to which measurements.

It is known from equations (2) and (5) that the values of $\delta I / I_0$, and consequently, those of f_d depend only on the a/b ratio (outer to inner collection volume radii) and not on the chamber size. This is confirmed by comparison of f_d shown in figure 1 for ionization chambers with radii of (4.9, 1.5 mm) and (8.0, 2.5), and also for those with (8.0, 1.5 mm) and (13.1, 2.5). The a/b ratio for these ionization chamber pairs are similar.

The good agreement between the experimental and theoretical values of f_d shown in figure 1, confirms the validity of equations (2) and (5). It also justifies equations (7)-(10) for volume recombination in cylindrical ionization chambers, and also confirms the utility of the method used in this paper for estimation of m, which depends on the ion lifetime and humidity.

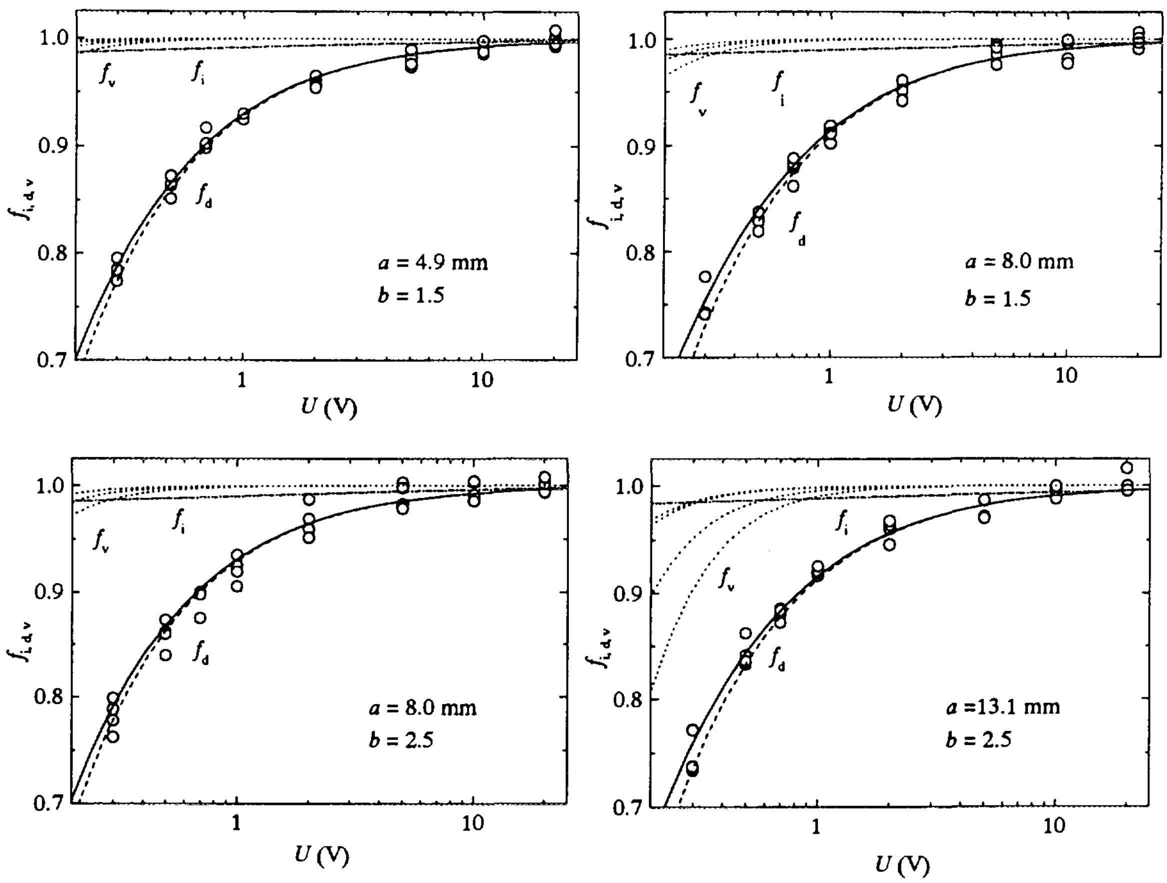

Fig. 1 Charge collection efficiencies f_d for diffusion loss in cylindrical ionization chambers which have a collection volume with outer and inner radii a and b: experimental result O, exact equation (2) ——, approximate equation (5) ------ . Collection efficiencies for initial recombination f_i ----- and volume recombination f_v ········ were used to obtain the values of O.

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