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Volume I

METHOD OF INCLINED VELOCITIES IN THE AIR ION MOBILITY ANALYSIS

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ABSTRACT: *Loscertales* [1998] proposed an inclined electric field in a mobility analyzer with the aim to suppress the Brownian broadening of the transfer function and improve the mobility resolution. The inclined field can be accomplished by using inclined grids as proposed by *Tammet* [1999]. The ways of realization of the method of inclined grids are described in the present paper. A low concentration of the ions necessitates intentional instrumental broadening of the transfer function in the atmospheric measurements. Thus the Brownian diffusion is not the main factor of mobility resolution in our case. However, the method of inclined grids has some unexpected at first advantages that make it to a promising method in atmospheric ion research. The main advantage is the reduced effect of random errors caused by the alpha decay of radon daughters deposited in the analyzer.

INTRODUCTION

The measurement of air ion mobility distribution is a key for understanding the role of ion-induced nucleation in the atmosphere. Traditional measurement methods are the drift tube or the time-of-flight method, and the aspiration method or the *method of transversal velocities*. An alternative *method of parallel velocities* proposed by *Zeleny* [1898] is forgotten today. Drift tubes are popular in high-resolution laboratory measurements. They make available the Brownian limit of mobility resolution $\delta = \delta_o = \sqrt{2kT/(qV)}$. The resolution of an aspiration condenser is worse, $\delta = \kappa\delta_o$, $\kappa > 1$, and the resolution of the Zeleny instrument is better, $\kappa < 1$. Aspiration condenser is still preferred in the atmospheric measurements in spite of the fact that its Brownian limit of resolution is low. *Loscertales* [1998] introduced the *method of inclined velocities* that composes high resolution ($\kappa < 1$) with the advantages of an aspiration condenser. Unfortunately, the technical realization remained an unsolved problem. Non-equipotential electrodes proposed by Loscertales encounter technological difficulties. A realistic way to accomplish the inclined field is the method of inclined grids proposed in the paper [*Tammet*, 1999].

PLAIN IGMA

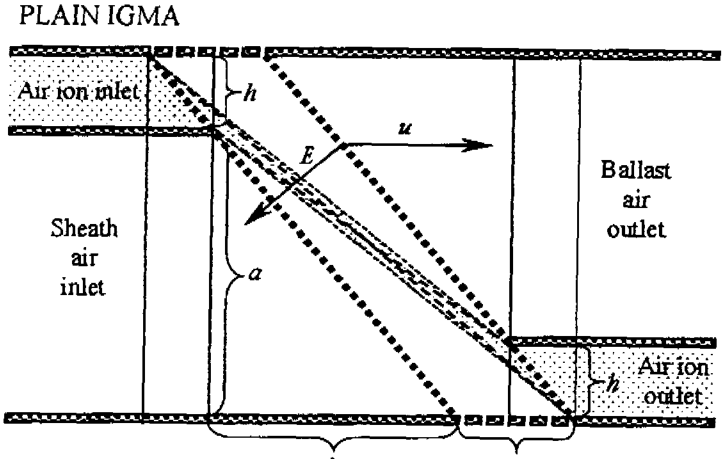

Figure 1. Cross section of a plain IGMA.

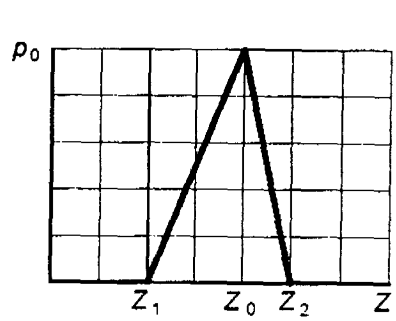

Figure 2. Diffusion-free transfer function of a plain IGMA.

The configuration of a plain Inclined Grid Mobility Analyzer (IGMA) is described in Figure 1. The air flow channel between two parallel plates is of the height of $a + h$ and of arbitrary width. Plug air flow is expected. The inlet of the air flow channel is divided into the air ion inlet and the filtered sheath air inlet. Equal heights of the sheath air inlet and the ballast air outlet enable to recirculate the sheath air to the ballast air. The air flow velocity u is parallel to the plates. The air passes two inclined grids. The driving voltage V is applied between the grids and the regions left and right of the grids are free of electric field. The sidewalls between the grids could be made as voltage dividers to keep the electric field E between the grids uniform. The diffusion free limiting trajectories of particles between the grids are shown in Figure 1. The triangular transfer function in Figure 2 expresses the probability of ions to reach the outlet depending on the mobility. The critical mobilities and the passage-through-grids probabilities are calculated by means of the method of fluxes described by *Tammet* [1970]:

$$Z_1 = \frac{ud}{V} \frac{1}{1 + (b/a)(b + d - bh/a)/(a - h)}, \qquad Z_2 = \frac{ud}{V} \frac{1}{1 + (b/a)(b + d + bh/a)/(a + h)},$$

$$Z_0 = \frac{ud}{V} \frac{1}{1 + (b/a)(b + d)/a}, \qquad p_0 = \frac{bd}{a^2 + b^2 + bd} \qquad \kappa = \frac{\sqrt{1 + \dfrac{d(b+d)}{a^2 + b^2 + bd}}}{\sqrt{1 + \dfrac{a^2 + b^2}{bd}}}.$$

IMPROVED IGMA

The plain IGMA has some features that are unfavorable in the atmospheric measurements. Two of these features are essential:

- high voltage should be applied between the inlet and outlet of ions, and if we wish to have the ion collector on the near-ground-potential, then a high potential will appear on the inlet;
- ion flow fills a small part of the space between the grids and thus the distance between the grids and the required potential is large.

These shortcomings can be eliminated when the grids are shortened so that they cover only the sheath air inlet and ballast air outlet, and leave the ion inlet and outlet free. Unfortunately, the electric field in the improved analyzer is complicated and the analytic calculation of the transfer function is impossible. The calculations can be performed when solving the Laplace equation by means of a numerical method. Some results of the model calculations are shown in Figures 3-6.

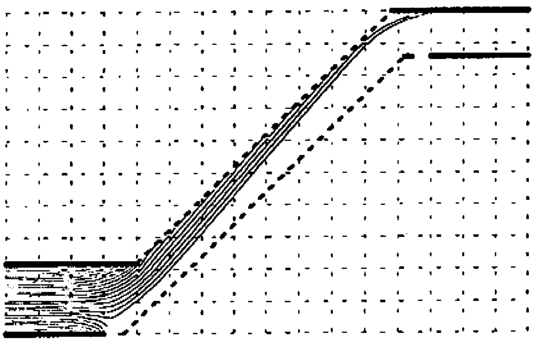

Figure 3. Trajectories of the ions of high mobility between the grids of an improved IGMA.

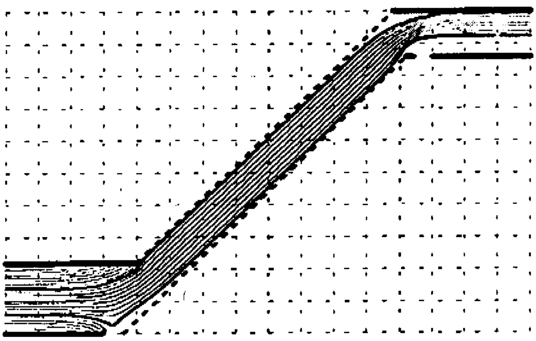

Figure 4. Trajectories of ions of the central mobility between the grids of an improved IGMA.

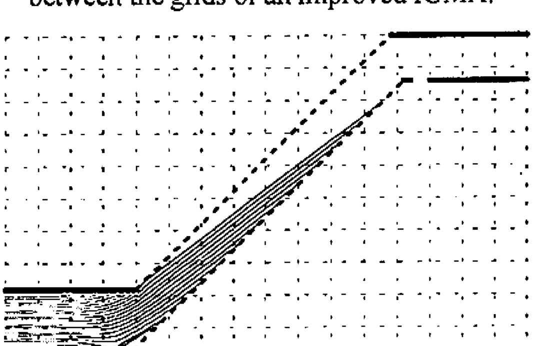

Figure 5. Trajectories of ions of the low mobility between the grids of an improved IGMA.

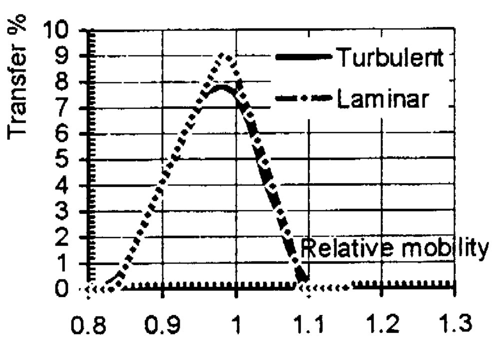

Figure 6. Transfer function of an improved IGMA. Relative intensity of turbulence 10% and relative correlation length 50%.

The analyzer consists of two grids inclined in 45 degrees from the air flow. The inlet of ions may be at the top as in Figure 1, or at the bottom as in Figures 3-5, it does not make any essential difference. Laminar plug flow is expected in Figures 3-5. Controlled high voltage is applied on the second inclined grid that is repelling the ions to be analyzed. All other components of the analyzer are on the ground potential. A potential divider or insulator (shown as a gap between the grid and a plate in figures) is expected to separate the high voltage deflector grid from the grounded horizontal plates. The ions of low mobility are mostly controlled by the air flow and they pass through the second grid. The ions of high mobility are mostly controlled by the electric field and if they appear between the grids, they will be deposited on the first grid. The ions of central mobility are passing through to the collector as shown in Figure 4. The resulting transfer function is shown in Figure 6, where the mobility is expressed in respect to the central 45-degree mobility. Figure 3 illustrates the passage of the ions of slightly higher mobility compared with the central mobility, and Figure 5 the passage of the ions of slightly lower mobility. The mathematical model of IGMA allows the including of the effect of turbulence. The effect of turbulence appears small due to the short correlation length of air flow velocity pulsations between the grids. A result of a model calculation is presented in Figure 6.

A specific shortcoming of the described design of IGMA lies in complicated aerodynamics, where the plug flow profile is not easy to maintain.

THE INSTRUMENT

An improved IGMA for the measurement of the atmospheric intermediate and small air ions has been designed at the Air Electricity Laboratory of University of Tartu and manufactured by a spin-off company AIREL Ltd. The instrument is intended for the study of nucleation events in the atmosphere and should have both the good sensitivity and high time resolution. The mobility range of 0.05–3.2 $cm^2 V^{-1} s^{-1}$ is logarithmically distributed into 18 fractions. The fraction concentrations are often below 10 cm^{-3} and huge air flow is required to assure the necessary sensitivity. The flow rate in the inlet slit is 0.05 m^3/s. The plug flow is not kept at the full height profile and the velocity of air passing the grids is less than in the ion inlet. The sheath air should be free of ions. A stack of plate electrodes is used as an electrostatic filter just before the grid. The effectiveness of this filter is sufficient to cut away the ions of the measured mobility but not sufficient to filter out the space charge carried by large air ions. The fluctuations of the space charge cause random errors or noise in measurements. Thus the ballast air is recirculated to the sheath air and passed on its way through a long electrostatic filter that essentially suppresses the noise of space charge fluctuations.

The ions in the outlet are collected by a well-insulated and shielded electrostatic filter powered by an internal battery and DC-DC converter. The collector is connected to the ground through an electrometric amplifier. Electrostatic shielding from the high voltage deflector grid allows free manipulation with mobility control voltage. The deflector grid is connected to a RC circuit with a time constant of about 4 s. The capacitor of this circuit is quickly charged up to 6 kV and slowly discharged through the resistor with a period of 20 s. This assures the logarithmical scanning of mobility from the lowest to the highest value of the mobility range during the 20 s period.

The air ion inlet is equipped with a controlled electrostatic filter that is used as a gate to close or open the ion entrance into the instrument. The 20 s scans are performed alternately with the closed and opened inlet gate that allows the effective suppressing of systematic errors. Data recording period is 3 minutes. During this period the mobility distribution is 9 times scanned through the full range of 0.05–3.2 $cm^2 V^{-1} s^{-1}$, five times with open inlet gate and four times with closed inlet gate.

The noise in the collected current limits the time and mobility resolution of the instrument. Two factors of noise appeared the most essential: the fluctuations of the space charge of the residue large ions that are not filtered out by the sheath air filter, and the noise generated by the ionization pulses generated by the alpha particles emitted by the deposited in the instrument radon daughters. The sheath air circulation through long electric filter allows suppressing the first factor of the noise. The alpha emission inside of the ion collector does not generate essential noise because the air gaps inside of the collector are small and both positive and negative ions are nearly equally collected. The ions generated by the alpha particles between the grids are separated by the electric field according to the polarity. If the characteristic mobility is low and the voltage is high, then the generated small ions are collected on the grids and do not reach the collector. If the characteristic mobility is just in the range of small ions, then the clouds of separated unipolar ions reach the collector and generate noise.

The noise of 18 mobility fractions was measured in an experiment when working for 10 hours with a permanently closed inlet gate. The result is shown in Figure 7. The effect of the alpha particle generated noise becomes essential when the characteristic mobility exceeds 1 $cm^2 V^{-1} s^{-1}$.

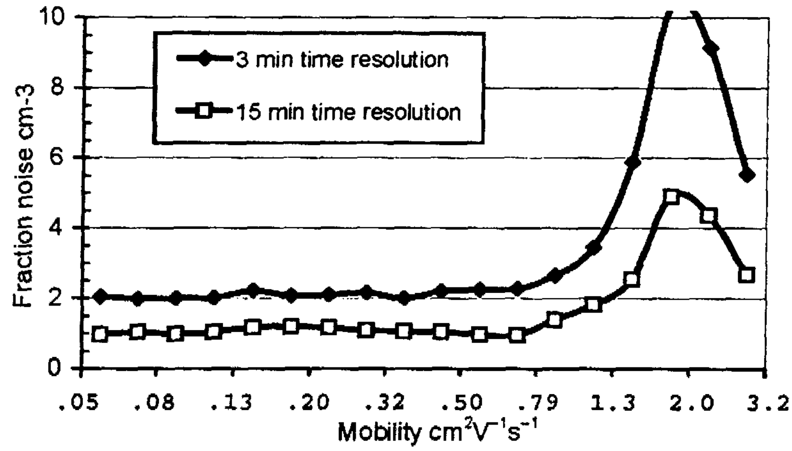

Figure 7. Dependence of the fraction concentration measurement noise on the characteristic mobility in IGMA.

Another mobility spectrometer for similar applications was designed and manufactured according to the traditional principle of an aspiration condenser. In this instrument the level of the alpha particle generated noise appears nearly independent of the characteristic mobility and its value is about the same as that in IGMA in the range of small ions. Here becomes evident the main advantage of IGMA in the atmospheric research: the suppression of the noise, when the characteristic mobility is less than the mobility of small ions. This is important in practice, because the sensitivity of the instrument is not critical in the range of small ions, where the ion concentration is considerable, and extra high sensitivity is required only in the mobility range of intermediate ions.

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