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Air ions and ion dynamics

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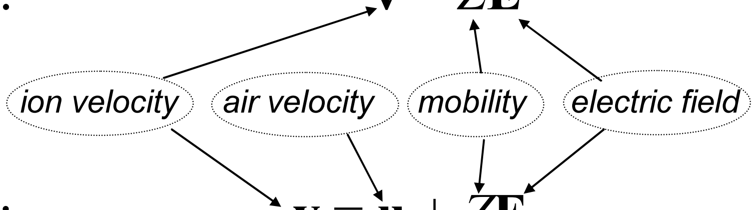
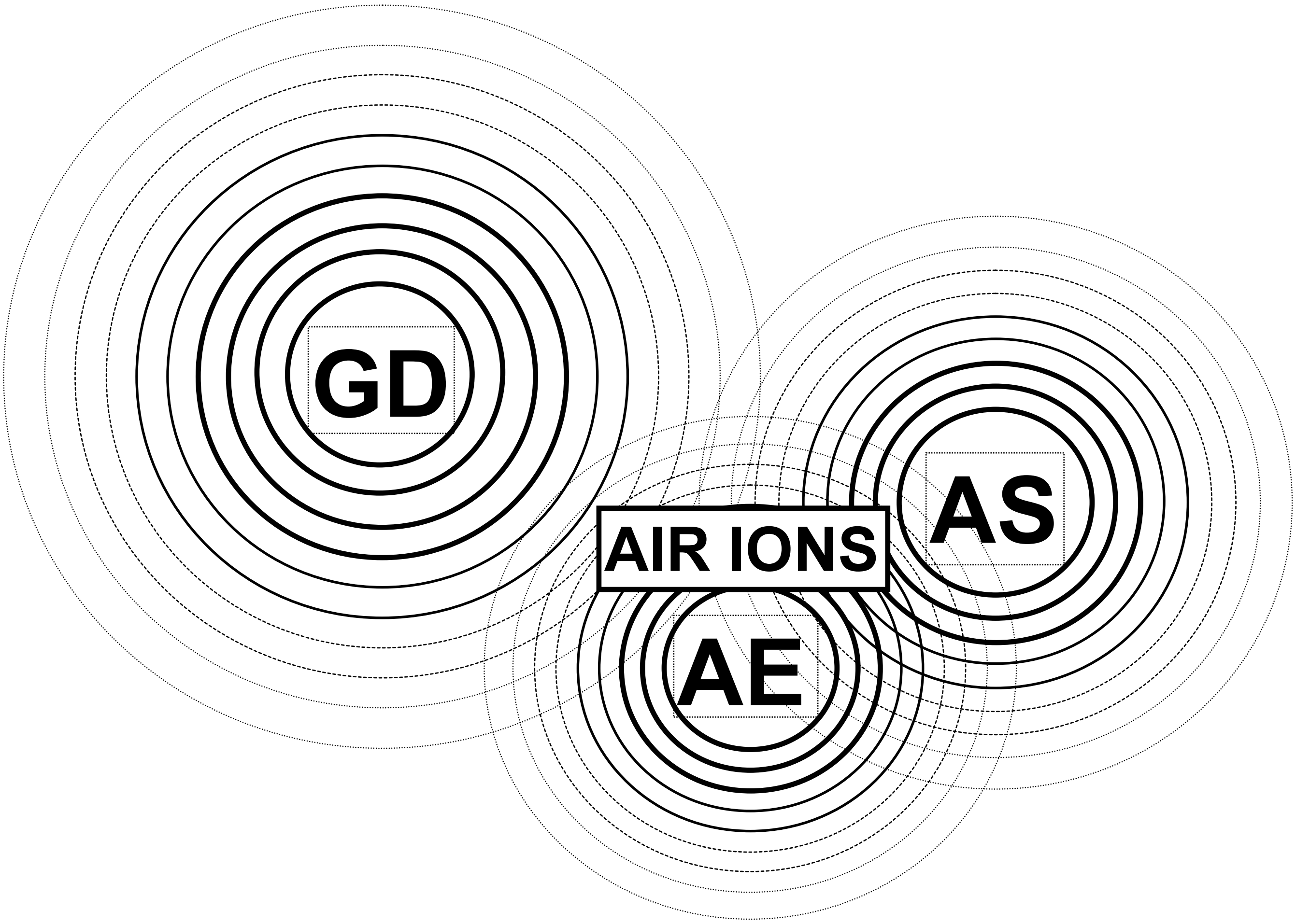
Air ion = a particle, which hydrodynamic Lagrangian drift is fully controlled by electrostatic force:

Linear model: $\mathbf{v} = Z\mathbf{E}$



Eulerian drift: $\mathbf{v} = \mathbf{u} + Z\mathbf{E}$



An illustration of the expanding research fields
and of the position of air ions as a common research subject.

GD – Gas Discharge and Plasma Physics,

AE – Atmospheric Electricity,

AS – Aerosol Science,

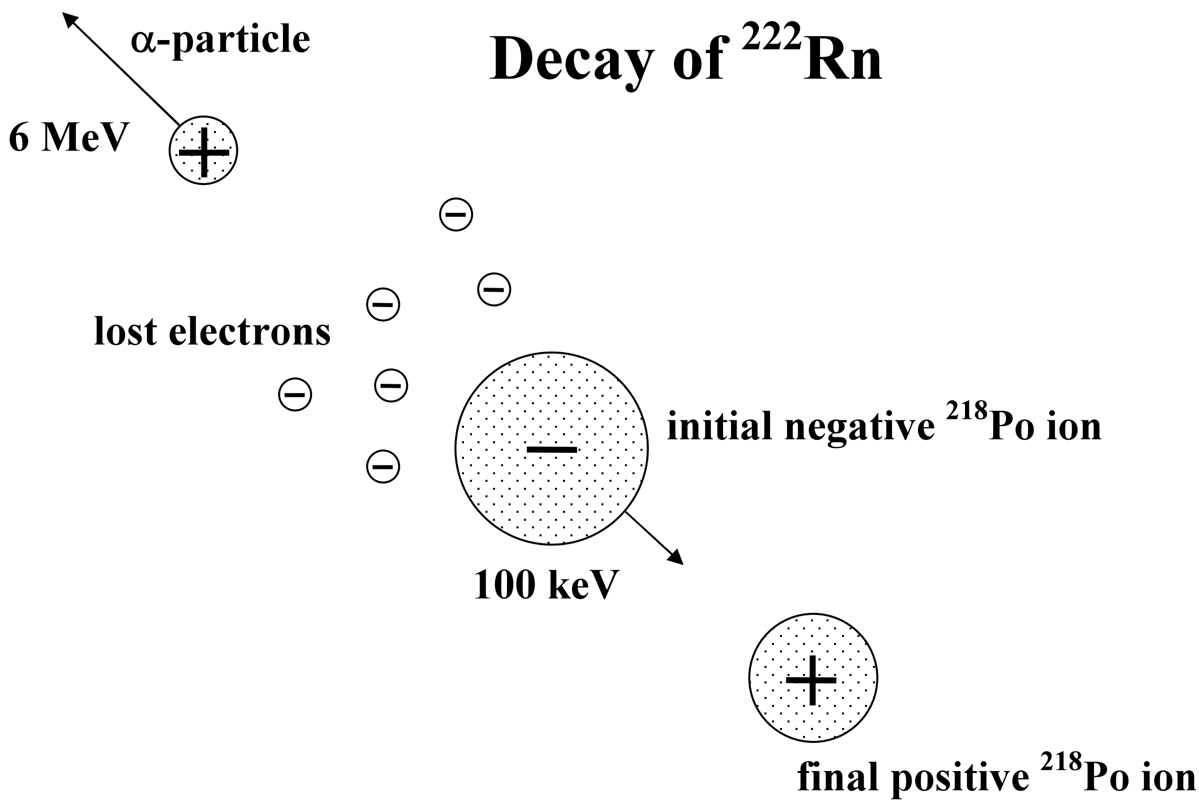
NEW – Analytic chemistry.

Popular topics (according to number of publications) and journals

Rank	**Topic**	**Journals**
1	Mobility Analyzers	*J. Aerosol Sci.* *Aerosol Sci. Technol.*
2	Physics and Chemistry of Air Ions	J. Atmos. Electr. Int. J. Mass Spectrom. J. Chem. Phys.
3	Ions in Tropospheric air	JGR Atmospheres Atmos. Res.
4	Ions and Radioactivity	*J. Aerosol Sci.* *Aerosol Sci. Technol*.
5	Applications of air ion measurements	Anal. Chem. *J. Aerosol Sci*.
6	Aerosol Electricity	*J. Aerosol Sci.*
7	Ion-induced Nucleation	*J. Aerosol Sci.* *Aerosol Sci. Technol.*

Ionizing radiations in nature

- *alpha radiation*
- *cosmic rays*
- *beta&gamma radiation*



Corona ions from powerlines and increased exposure to pollutant aerosols

A. P. FEWS*, D. L. HENSHAW, R. J. WILDING and P. A. KEITCH

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2.1. *Powerline corona ions*

High-voltage transmission lines suffer corona losses of up to 1 mA per metre (Abdel-Salam and Abdel- Aziz 1994). This corresponds with up to 6.25×10^{15} charges per metre per second of line. Much of this charge may be assumed to be absorbed by the line and the pylon, but in absolute terms it must also be assumed that a substantial flux of ions can be continuously emitted into the atmosphere......

Twentieth century atmospheric electrical measurements at the observatories of Kew, Eskdalemuir and Lerwick

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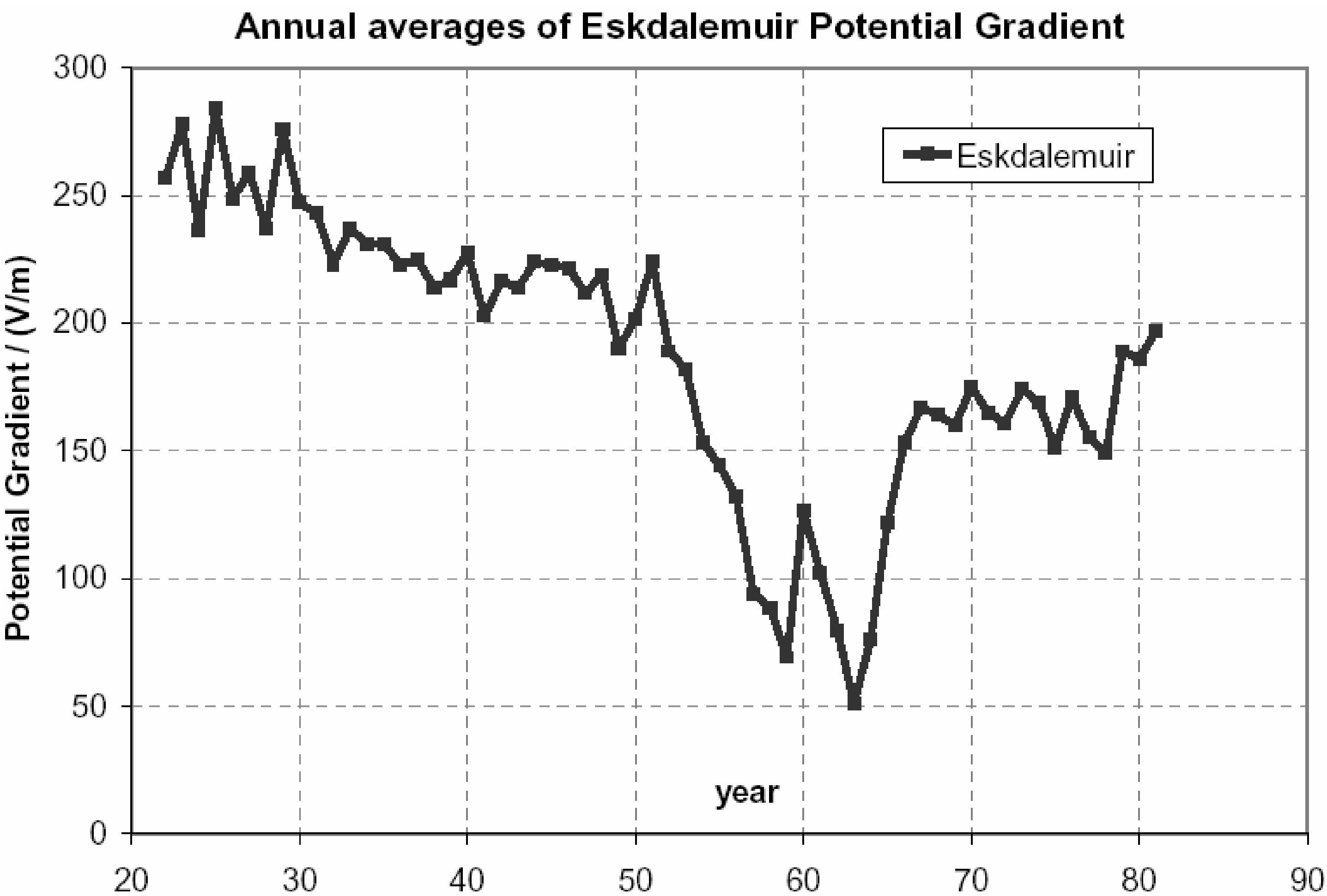

Krypton-85 pollution and atmospheric electricity

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Abstract

Krypton-85 is a chemically inert radioactive gas present in the atmosphere, concentrations of which have been greatly increased by nuclear reprocessing and weapons testing since 1945. The long half-life (10.7 yr), allows the gas to mix thoroughly in the atmosphere. Ionization caused by Krypton-85 increases the electrical conductivity of atmospheric air. Further increases in krypton-85 emissions seem inevitable. The increase in air conductivity due to release of krypton-85 will vary with height, and be larger over the oceans than over the land. Increases in conductivity will produce uncertain effects on atmospheric phenomena, so changes are compared in magnitude with other factors perturbing the conductivity, such as combustion aerosol burdens, volcanic eruptions and nuclear weapons testing. Conductivity changes are expected to have the greatest significance for meteorological phenomena close to the source.

Evolution of negative small air ions at two different temperatures

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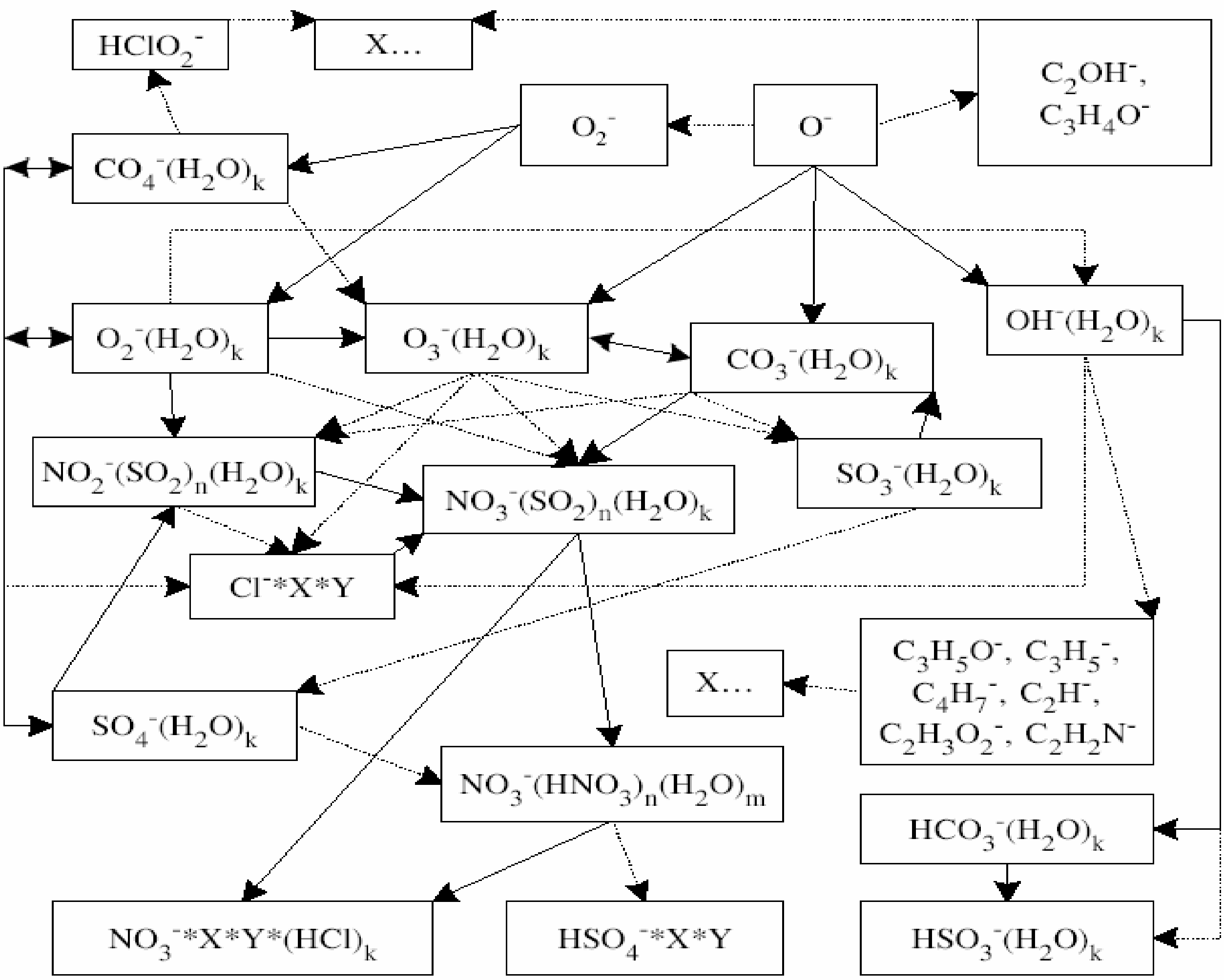
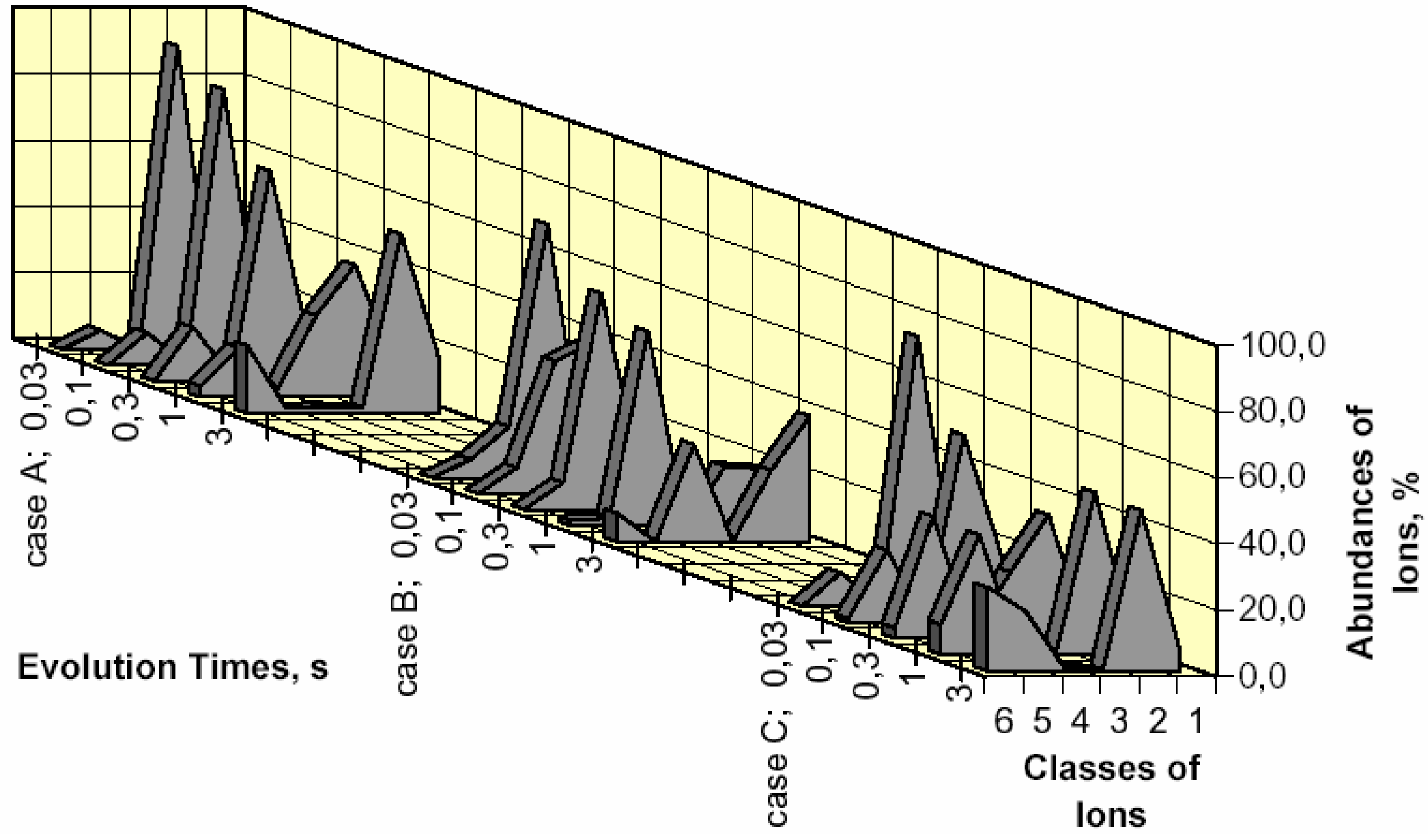
Abstract— The evolution of negative air ions is mathematically simulated considering 151 ions, 66 trace gases and 493 ion-molecule reactions. The main attention is paid to the evolution interval from 30 ms to 3 s where the knowledge is most limited. Recently, detailed experimental data about the time and temperature variation of the air ion mobility spectrum became available, therefore the results of mathematical simulation now can be compared with the observed ones. Unfortunately, the measurements have not been accompanied by data about concentrations of trace gases, therefore the provided results can be interpreted ambiguously. Nevertheless, the main features of the measured ion evolution shape can be simulated, and the composition of trace gases likely responsible for the observed shape can be derived. In this case, in the studied evolution interval mainly the transformation $O_2^-(H_2O)_n \rightarrow CO_3^-(H_2O)_m \rightarrow NO3^-\times X\times Y$ takes place. At the higher temperature, the ions $CO_3^-(H_2O)_m$ are less abundant. In the respective steady (natural) state the most abundant ions are $NO_3^-\times X\times Y\times(HCl)_n$ and $NO_3^-(H_2O)_m$. At the higher temperature, the ions $NO_3^-(H_2O)_m$ are dominant.





$$\frac{dn_+}{dt} = q - \alpha n_+ n_- - g_+ n_+$$

(q: m^{-3}s^{-1}; α: m^{3}s^{-1}; g_+: s^{-1})

$$\frac{dn_-}{dt} = q - \alpha n_+ n_- - g_- n_-$$

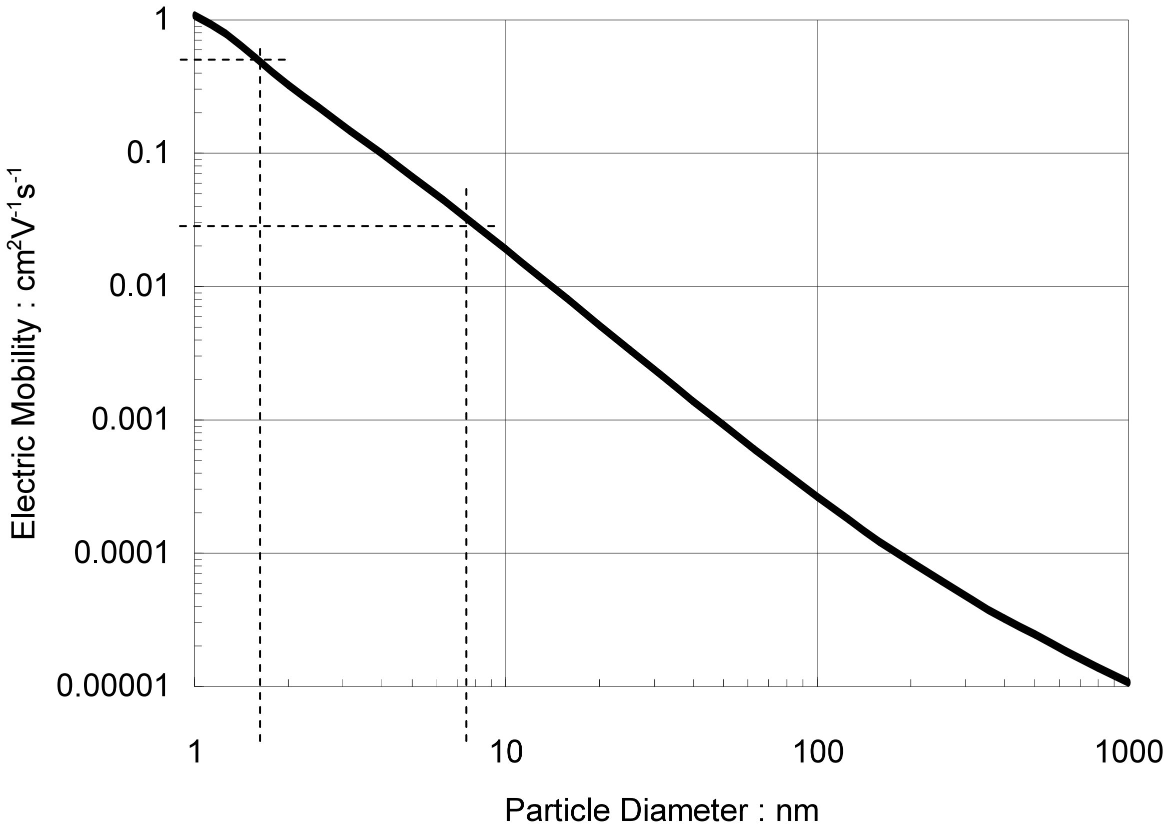
$$\frac{dn}{dt} = q - \alpha n^2 - gn \qquad q = \alpha n^2 + gn$$

(αn^2: 3%; gn: 97%)

$$g \approx (2 \times 10^{-5}\,\mathrm{m}^2/\mathrm{s})\; N_d$$

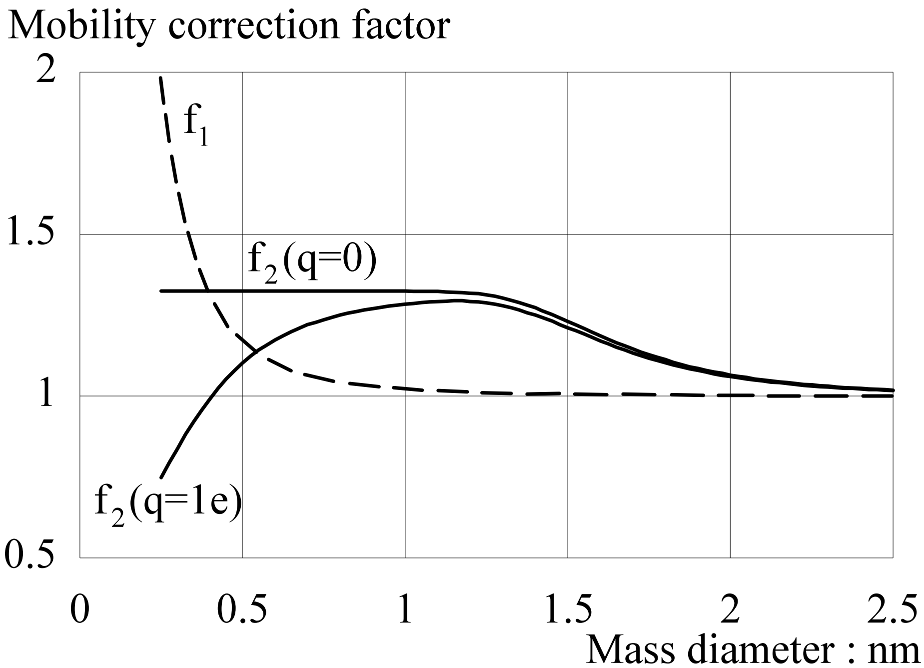
(N_d: m^{-2} = m / m^{3})

Mobility



Diameter-mobility relation for single charged particles
(Air, standard pressure, 20ºC)

Ion or Particle?



Dependence of the mobility correction factors on the size of neutral and single-charged particles in air. Standard conditions and the particle density of 2 g cm^{-3} assumed.

The scattering law is just the effect of the structure of the internal energy of the particle. If the internal energy levels are frozen during the collisions, the particles should be considered to be molecules or clusters. If the internal energy levels are melted out, then the scattering of the molecules is inelastic and a particle can be considered to be a macroscopic body. Thus, the curve of f_2 illustrates the transfer from the molecular or cluster state into the macroscopic particle state. Particles of diameter below 1.4 nm could be called the clusters or molecules and particles of diameter above 2 nm could be called macroscopic particles according to the dominant mechanism of energy transfer by collisions

FLUX OF AIR IONS

Monomobile air ions:

Electric current through an element of surface **dS**:

flow rate **u dS** electric flux ***E* dS**

$$\mathrm{d}I = \rho\, \mathbf{v}\, \mathbf{dS} = \rho(\mathrm{d}\Phi + Z\,\mathrm{d}N)$$

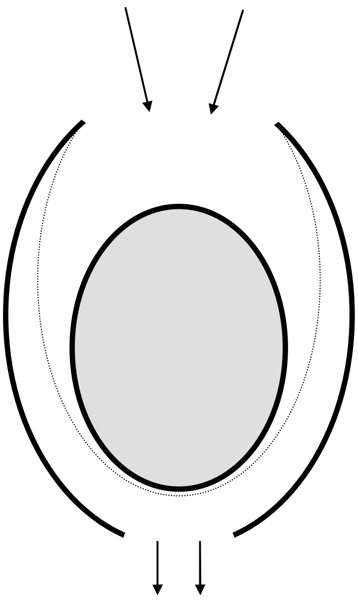
Electric current through a surface S

$$I = \iint_S \rho\left(\mathrm{d}\Phi + Z\,\mathrm{d}N\right) = \bar{\rho}\left(\Phi + ZN\right)$$

For any flow surface of monomobile air ions

$$\Phi + ZN = 0$$

EXAMPLE: DMA CHARACTERISTIC MOBILITY



$$\Phi + ZN = 0$$

$$Z = -\frac{\Phi}{N}$$

$$N = \frac{Q}{\varepsilon_\circ} = \frac{CV}{\varepsilon_\circ}$$

$$Z = -\frac{\varepsilon_\circ \Phi}{Q} = -\frac{\varepsilon_\circ \Phi}{CV}$$

CAGNIARD THEOREM

1. From Eulerian position:

charge conservation & *convection current*

$$\frac{\partial\rho}{\partial t} = -\operatorname{div}\mathbf{j} \quad \& \quad \mathbf{j} = \mathbf{v}_{ion}\rho \quad \Rightarrow \quad \frac{\partial\rho}{\partial t} = -\rho\operatorname{div}\mathbf{j} - \mathbf{v}_{ion}\operatorname{grad}\rho$$

2. From Lagrangian position:

dρ – complete differential in a point drifting along with air ions.

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = \frac{\partial\rho}{\partial t} + \mathbf{v}_{ion}\operatorname{grad}\rho = -\rho\operatorname{div}\mathbf{v}_{ion}$$

$$\mathbf{v}_{ion} = \mathbf{v}_{air} + Z\mathbf{E} \quad \Rightarrow \quad \operatorname{div}\mathbf{v}_{ion} = \operatorname{div}\mathbf{v}_{air} + Z\operatorname{div}\mathbf{E} = Z\frac{\rho}{\varepsilon_\circ}$$

Equation: $\dfrac{\mathrm{d}\,\rho}{\mathrm{d}\,t} = -\dfrac{Z}{\varepsilon_\circ}\rho^2$ Solution: $\rho = \dfrac{\rho_\circ}{1 + \dfrac{Z\rho_\circ}{\varepsilon_\circ}t}$

Autodilution factor: $1 + \dfrac{Z\rho_\circ}{\varepsilon_\circ}t$ Critical time: $t_\circ = \dfrac{\varepsilon_\circ}{Z\rho_\circ}$

Example: 10^5 single-charged particles per ccm
$Z = 1$ cm^{2}V^{-1}s^{-1}
$t_o = 5.5$

$\rho_o = \infty \Rightarrow \rho = \dfrac{\varepsilon_\circ / Z}{t}$ $Z = 1.5$ cm^2/Vs $\Rightarrow \varepsilon_o/Z = 370000$ e/cm^3

EFFECT OF MOLECULAR DIFFUSION

Alternative theoretical models:

1) **Eulerian** – Fick equation
2) **Lagrangian** – Brownian motion

1. TOF (Time Of Flight) spectrometer. Ions are drifting in uniform electric field in calm air. Distance is given and time is measured. Metrological quasiequivalent: time is given and distance is measured.

Distance $d = ZEt$ relative error $E_{ZD} = E_d$.

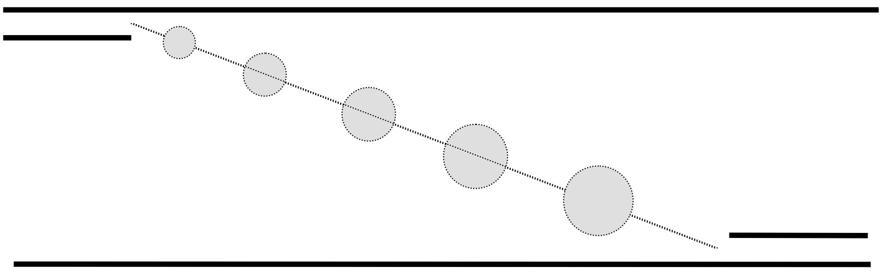
As shown by Einstein, Brownian deflection of the distance is distibuted according to Gauss law with a standard deviation of

$$\sigma_d = \sqrt{2\frac{kTZ}{q}t} \ .$$

Distance can be expressed as $d = \sqrt{ZVt}$. It follows

$$E_{ZD} = E_d = \frac{\sigma_d}{d} = \sqrt{\frac{2kT}{qV}}$$

2. Plain DMA.



The effect of Brownian motion along the electric field is the same as in TOF. It is combined with the effect of Brownian motion along the air flow

$$E_{ZD} = \sqrt{E_d^2 + E_l^2}$$

$$\sigma_l = \sigma_d \quad \Rightarrow \quad E_l = \frac{\sigma_d}{l} = \frac{d}{l} E_d$$

$$E_{ZD} = \sqrt{\left(1 + \frac{d^2}{l^2}\right) \frac{2kT}{qV}}$$

or

$$\mu_D = 1 + \frac{d^2}{l^2} \qquad \& \qquad E_{ZD} = \sqrt{\mu_D \frac{2kT}{qV}}$$