Journal of Electrostatics 71 (2013) 781–784

Contents lists available at SciVerse ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Simplified classification of atmospheric charged particles

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ARTICLE INFO

Article history:
Received 27 August 2012
Received in revised form
12 December 2012
Accepted 13 December 2012
Available online 19 January 2013

Keywords:
Charged atmospheric particles
Ultrafine aerosol particles
Cluster ions
Balance equation
Recombination/attachment coefficients

ABSTRACT

One of the most important problems on the atmospheric studies is electrostatic interaction between atmospheric cluster ions and aerosol particles.

Atmospheric ions are currently classified into 5 overlapping categories having mobilities ranging from 1.3 $cm^2\ V^{-1}\ s^{-1}$ to less than 0.004 $cm^2\ V^{-1}\ s^{-1}$.

We have considered charged ultrafine aerosols and cluster ions as charged atmospheric particles. This classification can be used in the interpretation of electrostatic interactions among these particles.

Attachment processes between ultrafine aerosols can be considered as recombination processes between charged atmospheric particles. Atmospheric particles are grouped into two categories, but the number of recombination and attachment coefficients is not reduced.

1. Introduction

Atmospheric electricity is a wide field of study. Principle elements of atmospheric electricity are cluster ions and aerosol particles, air conductivity and atmospheric electric fields [1,2].

The first group of atmospheric particles, cluster ions consist on nucleus ions surrounded by several water molecules. In normal atmospheric conditions most abundant atmospheric cluster ions are:

$$\text{positive cluster ions}: \quad H^+(H_2O)_n, (H_3O)^+(H_2O)_n, \left(NH_4^+\right)^+(H_2O)_n,$$
$$\text{and negative cluster ions}: \quad O_2^-(H_2O)_n, OH^-(H_2O)_n, \left(NO_3^-\right)^+(H_2O)_n, \left(HSO_4^-\right)^+(H_2O)_n.$$

where n is the number of water molecules, and can be about 8–12, depending on the polarity of nucleus ion as well as on atmospheric conditions [3,4]. In some cases n reach large values, up to 60.

The distribution of ion species depends on the ion's age and strongly on the concentration and types of impurities and trace gases in the air [5].

Atmospheric ion spectrum contains two modes, one corresponding to the small ions at about 1.5 $cm^2\ V^{-1}\ s^{-1}$ and a second large ion line at about $3{\cdot}10^{-4}\ cm^2\ V^{-1}\ s^{-1}$. The spectral region between these two lines is populated by the intermediate ions. Beyond the large ions, the spectrum continues with the giant or ultra-large ions [6,7].

Different electrical mobility categories in an ion mobility spectrum are inversely related to ionic mass and radius. Ion mobility spectrum provides useful information to understand the interactions of ions and aerosols in the Earth's atmosphere in characterizing the freshly nucleated charged particles with diameters less than 3 nm in linking the electrical parameters to chemical properties of the atmosphere.

The ion mobility spectra have often been used to estimate particle size distributions although there is no general law relating mobility of an ion to its size in the entire range of charged particles.

The second group of atmospheric particles consists of aerosol particles [8]. These particles can be in solid or liquid form, and

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http://dx.doi.org/10.1016/j.elstat.2012.12.029

chemically can be composed by various compounds [9,10]. From electrostatic viewpoint, based on their electric charge, these particles can be classified as charged and neutral particles [11,12]. Atmospheric aerosol particles range in size over more than four orders of magnitude, from freshly nucleated clusters containing a few molecules to cloud droplets and crustal dust particles up to tens of microns in size [13].

Generally speaking, according to their size, aerosol particles are much greater than cluster ions [14]. The greater mobilities of cluster ions makes them an important factor on atmospheric electricity [15,16].

The classification of air ions and charged aerosols is as below [17,18]:

- Small cluster ions: mobility 1.3–2.5 cm^2 V^{-1} s^{-1} (diameter 0.36–0.85 nm and mass 30–400 u).
- Big cluster ions: mobility 0.5–1.3 cm^2 V^{-1} s^{-1} (diameter 0.85–1.6 nm and mass 400–2500 u).
- Intermediate ions: mobility 0.034–0.5 cm^2 V^{-1} s^{-1} (diameter 1.6–7.4 nm). The corresponding class of aerosol particles is the fine nanometer particles.
- Light large ions: mobility 0.0042–0.034 cm^2 V^{-1} s^{-1} (diameter 7.4–22 nm). The corresponding class of aerosol particles is the ultrafine particles or coarse nanometer particles.
- Heavy large ions: mobility $<$ 0.0042 cm^2 V^{-1} s^{-1} (diameter $>$ 22 nm). The corresponding class of aerosol particles could be called the Aitken particles.

A mobility of 0.5 cm^2 V^{-1} s^{-1} (diameter 1.6 nm) is the boundary, which has been considered physically as the boundary between molecular clusters and macroscopic particles. The same value was also formerly considered as the lower boundary of small air ions. On the other hand, aerosol particles are classified in these size modes:

Nucleation	3 nm $< d <$ 20 nm
Atiken	20 nm $< d <$ 90 nm
Accumulation	90 nm $< d <$ 1000 nm
Coarse	1µm $< d <$ 100 µm

where d is particle diameter.

It must be mentioned also that atmospheric particles have also an important impact on health [19]. The effects depend on their number concentrations and their size distributions.

Charge level of atmospheric particles depends primarily on their size [20–22]. Over a size limit can be applied the modified Boltzmann distribution for the number of electric charges carried by an aerosol particle [23,24].

The analytical form of this distribution is given in eq. (1).

$$\frac{N_{\mathrm{j}}}{N_{\mathrm{o}}} = \left[\frac{n_+\mu_+}{n_-\mu_-}\right]^{\mathrm{j}}\left(\frac{8\pi\varepsilon_0 akT}{je^2}\right)\sinh\left(\frac{je^2}{8\pi\varepsilon_0 akT}\right)\exp\left[\frac{-je^2}{8\pi\varepsilon_0 akT}\right] \quad (1)$$

where,

N_{j} is number of aerosol particles which carry j electric charges
N_{o} is number of neutral aerosol particles,
j is number of elementary charges
a is aerosol diameter
$\mu_\pm$ is ion mobility for both polarities
T is ambient temperature
ε_0 is the permittivity of free space
k is Boltzmann constant

The mean charge for aerosol particles is:

$$\bar{j} = \frac{4\pi\varepsilon_0 akT}{e^2}\ln\left[\frac{n_+\mu_+}{n_-\mu_-}\right] \quad (2)$$

Eq. (2) can be applied for bipolar charging in free molecular conditions. Under these conditions, both mean free paths of positive and negative ions are much larger than characteristics of aerosols.

The theory of Fuchs [25], requires five ion properties to calculate the charging probabilities: Electrical mobility, mass, diffusion coefficient, mean thermal velocity, and mean free path. Only two of these properties are independent; usually, ion mobility and mass are used to derive the other properties [26].

The presence of both air ions and aerosol particles indicates also the level of air pollution in the measurement region.

2. Theory

This paper deals with a useful definition of atmospheric particles according to their electrostatic properties. The atmospheric particles under investigation are air ions and aerosol particles. These atmospheric particles can be grouped according to their size as well as to their charge level. This classification simplifies the usage of the balance equation (eq. (5)) when we treat ultrafine atmospheric aerosols.

One of the most important problems on the atmospheric studies is electrostatic interaction between atmospheric cluster ions and aerosol particles [27,28]. This phenomenon plays a key role not only on the atmospheric electricity (modifying the air conductivity), but also on other atmospheric processes, like new particle formations [29–32].

The fundamental equation which determines ion concentrations is balance equation [33–35], which in general form can be expressed by eq. (3).

$$\frac{\mathrm{d}n}{\mathrm{d}t} = q - \alpha n^2 - \beta nZ \quad (3)$$

where,

n – ion concentration
Z – aerosol concentration
q – ion production rate
α – recombination coefficient
β – attachment coefficient

Using stationary conditions ($\mathrm{d}n/\mathrm{d}t = 0$), balance equation takes the simplest form:

$$\alpha n^2 + \beta nZ = q \quad (4)$$

In more complex situations, we treat ions and aerosols of both polarities and neutral aerosols. In eq. (3) other terms must be added to characterize electrostatic interactions between ions and aerosols of opposite polarities [36].

In this case eq. (4) can be transformed as follow:

$$\alpha n_+n_- + \beta_{+-}n_+Z_- + \beta_{-+}n_-Z_+ + \beta_{+0}n_+Z_0 + \beta_{-0}n_-Z_0 = q_+ + q_- \quad (5)$$

where,

$n_\pm$ - ion concentration of each polarity
$Z_\pm$ - aerosol concentration of each polarity
$q_\pm$ - ion production rate of each polarity