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Determination of particle size distribution — Differential electrical mobility analysis for aerosol particles

Détermination de la distribution granulométrique — Analyse de mobilité électrique différentielle pour les particules d'aérosol

ICS: 19.120

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 24/SC 4 *Particle characterization*.

This second edition cancels and replaces the first edition (ISO 15900:2009), which has been technically revised.

The main changes compared to the previous edition are as follows:

[to be completed]

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Differential electrical mobility classification and analysis of airborne particles has been widely used to measure a variety of aerosol particles ranging from nanometre-size to micrometre-size in the gas phase. In addition, the electrical mobility classification of charged particles can be used to generate mono-disperse particles of known size for calibration of other instruments. One notable feature of these techniques is that they are based on simple physical principles. The techniques have become important in many fields of aerosol science and technology, e.g. aerosol instrumentation, production of materials from aerosols, contamination control in the semiconductor industry, atmospheric aerosol science, characterization of engineered nanoparticles, and so on. However, in order to use electrical mobility classification and analysis correctly, several issues, such as the slip correction factor, the ion-aerosol attachment coefficients, the size-dependent charge distribution on aerosol particles and the method used for inversion of the measured mobility distribution to the aerosol size distribution, need due caution.

There is, therefore, a need to establish an International Standard for the use of differential electrical mobility analysis for classifying aerosol particles. Its purpose is to provide a methodology for adequate quality control in particle size and number concentration measurement with this method.

Determination of particle size distribution — Differential electrical mobility analysis for aerosol particles

1 Scope

This International Standard provides guidelines on the determination of aerosol particle size distribution by means of the analysis of electrical mobility of aerosol particles. This measurement is usually called “differential electrical mobility analysis for aerosol particles”. This analytical method is applicable to particle size measurements ranging from approximately 1 nm to 1 µm. This International Standard does not address the specific instrument design or the specific requirements of particle size distribution measurements for different applications, but includes the calculation method of uncertainty. In this International Standard, the complete system for carrying out differential electrical mobility analysis is referred to as DMAS (differential mobility analysing system), while the element within this system that classifies the particles according to their electrical mobility is referred to as DEMC (differential electrical mobility classifier).

NOTE This International Standard does not include technical requirements and specifications for the application of DMAS, which should be defined in application specific standards or guidelines, e.g. for road vehicle applications (ISO/TC 22), environmental measurements (ISO/TC 146, CEN/TC 264) or nanotechnologies (ISO/TC 229).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC Guide 98: 2008, Guide to the Expression of Uncertainty in Measurement (GUM)

ISO 27891: 2015, Aerosol particle number concentration – Calibration of condensation particle counters

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
aerosol
system of solid or liquid particles suspended in gas

3.2
attachment coefficient
attachment probability of ions and aerosol particles

3.3
bipolar charging
process which attains a conditioned charge distribution of both positive <u>and</u> negative charges on aerosol particles

3.4
bipolar charge conditioner
device which attains a conditioned charge distribution of both positive and negative charges on aerosol particles

3.5
charging
processes that leave aerosol particles with size dependent specific distributions of unipolar or bipolar electrical charges

3.6
charge conditioner
device (or component of a DMAS) which establishes a known conditioned size dependent charge distribution on aerosol particles which are passed through it

3.7
charge distribution function
mathematical and/or empirical description of a conditioned particle size dependent charge distribution

3.8
condensation particle counter
CPC
instrument that measures the particle number concentration of an aerosol

NOTE 1 The sizes of particles detected are usually smaller than several hundred nanometres and larger than a few nanometres.

NOTE 2 A CPC is one possible detector for use with a DEMC.

NOTE 3 In some cases, a condensation particle counter may be called a condensation nucleus counter (CNC).

3.9
conditioned charge distribution
distribution of unipolar or bipolar electrical charges on aerosol particles defined by a charge distribution function, which is in a steady state for a sufficiently long period of time in an aerosol instrument downstream of a unipolar or bipolar charge conditioner

3.10
critical mobility
instrument parameter of a DEMC that defines the electrical mobility of aerosol particles that exit the DEMC in aerosol form, which may be defined by the geometry, sample and sheath flow rates, and electrical field intensity

NOTE Particles larger or smaller than the critical mobility migrate to an electrode or exit with the excess flow and do not exit from the DEMC in aerosol form.

3.11
differential electrical mobility classifier
DEMC
classifier that is able to select aerosol particles according to their electrical mobility and pass them to its exit

NOTE 1 A DEMC classifies aerosol particles by balancing the electrical force on each particle with its aerodynamic drag force in an electrical field. Classified particles are in a narrow range of electrical mobility determined by the operating conditions and physical dimensions of the DEMC, while they can have different sizes due to difference in the number of charges that they have.

NOTE 2 Another common acronym for the DEMC is DMA.

3.12
differential mobility analysing system
DMAS
system to measure the size distribution of submicrometre aerosol particles consisting of a charge conditioner, a DEMC, flow meters, a particle detector, interconnecting plumbing, a computer and suitable software

NOTE Another common acronym for the DMAS is MPSS (Mobility Particle Size Spectrometer).

3.13
electrical mobility
mobility of a charged particle in an electrical field

NOTE Electrical mobility can be defined as the migration velocity dependent on the strength of the electrical field, the mechanical mobility and the number of charges per particle.

3.14
electrometer
device that measures electrical current ranging from about 1 femtoampere (fA) to about 10 picoamperes (pA)

3.15 equivalent particle diameter
d
diameter of a sphere with defined characteristics which behaves under defined conditions in exactly the same way as the particle being described

NOTE Particle diameter (or simply diameter) used throughout this International Standard always refers to the electrical mobility equivalent diameter, which defines the size of charged particles with the same electrical mobility or the same terminal migration velocity in still air under the influence of a constant electrical field.

[SOURCE: ISO 27891]

3.16
Faraday cup aerosol electrometer
FCAE
electrometer designed for the measurement of electrical charge concentration carried by an aerosol

[SOURCE: ISO 27891]

NOTE A Faraday cup aerosol electrometer consists of an electrically conducting and electrically grounded cup as a guard to cover the sensing element that includes aerosol filtering media to capture charged aerosol particles, an electrical connection between the sensing element and an electrometer circuit, and a flow meter.

3.17
Knudsen number
Kn [ISO]
ratio of gas molecular mean free path to the radius of the particle, which is an indicator of free molecular flow versus continuum gas flow

3.18
laminar flow
gas flow with no temporally or spatially irregular activity or turbulent eddy flow

3.19
migration velocity
steady-state velocity of a charged airborne particle within an externally applied electric field

3.20
plateau detection efficiency
mean detection efficiency of a CPC in the size range which is not biased by particle size

[SOURCE: ISO 27891 “plateau efficiency”]

3.21
Reynolds number
Re [ISO]
dimensionless number expressed as the ratio of the inertial force to the viscous force; for example, applied to an aerosol particle or a tube carrying aerosol particles

3.22
slip correction
S_C
dimensionless factor that is used to correct the drag force acting on a particle for non-continuum effects that become important when the particle size is comparable to or smaller than the mean free path of the gas molecules

3.23
Stokes' drag
drag force acting on a particle that is moving relative to a continuum fluid in the creeping flow (low Reynolds number) limit

3.24
transfer function
ratio of particle concentration at the outlet of a DEMC to the particle concentration at the inlet of the DEMC, which is normally expressed as a function of electrical mobility

3.25
unipolar charge conditioner
device which attains a conditioned charge distribution of either positive or negative charges on aerosol particles

3.26
unipolar charging
process which attains a conditioned charge distribution of positive or negative charges on aerosol particles

4 Symbols

For the purposes of this document, the following symbols are applied.

Symbol	Quantity	SI Unit
A, B, C	elements of the slip correction factor defined in Equation (2)	dimensionless
c	thermal velocity of an ion or molecule	$\mathrm{m\ s^{-1}}$
D	diffusion coefficient of a particle or an ion in air	$\mathrm{m^2\ s^{-1}}$
d	aerosol particle diameter	m
E	electric field strength in a DEMC	$\mathrm{V\ m^{-1}}$
ε	relative error	
e	elementary charge $= 1{,}602\ 177 \times 10^{-19}$ C	
Kn	Knudsen number	
k	Boltzmann constant $= 1{,}381 \times 10^{-23}\ \mathrm{J\ K^{-1}}$	
L	effective active length of a DEMC, approximated by the axial distance between the midpoint of the aerosol entrance and the midpoint of the exit slit of a cylindrical DEMC	m
l	mean free path of a molecule	m
L_{Tube}	Length of a tube	m
M	molecular mass of air	amu
m	mass of an ion	amu
N	number concentration of aerosol particles, note that C_N is widely used as well.	$\mathrm{m^{-3}}$
N_{A}	Avogadro constant $\approx 6{,}022\ 141\ 79(30) \times 10^{23}\ \mathrm{mol^{-1}}$	
N_{I}	number concentration of ions	$\mathrm{m^{-3}}$
P	atmospheric pressure	Pa
p	number of elementary charges on a particle	(dimensionless)
q_1, q_2, q_3, q_4	flow rates of air (or gas) and of aerosol entering and exiting a DEMC	$\mathrm{m^3\ s^{-1}}$
Q_{a}	aerosol air flow rate	$\mathrm{m^3\ s^{-1}}$
r_1	outer radius of inner cylinder of a cylindrical DEMC	m
r_2	inner radius of outer cylinder of a cylindrical DEMC	m
Re	Reynolds number	(dimensionless)
S	Sutherland constant (=110,4 K at 23 °C and standard atmospheric pressure)	
S_{C}	slip correction	(dimensionless)
T	absolute temperature	K

Symbol	Quantity	SI Unit
t	residence time of an ion	s
U	DC voltage used to establish an electrical field in a DEMC	V
V	Volume	m^3
Z	electrical mobility of a charged aerosol particle	$m^2\ V^{-1}\ s^{-1}$
Z_1, Z_2, Z_3, Z_4	critical electrical mobilities that describe the transfer function of a DEMC	$m^2\ V^{-1}\ s^{-1}$
β	attachment coefficient of ions onto aerosol particles	$m^3\ s^{-1}$
γ	recombination coefficient of ions	(dimensionless)
δ	radius of a limiting sphere	m
μ_{gas}	coefficient of dynamic viscosity of a gas	$kg\ m^{-1}\ s^{-1}$
λ	mean free path of an ion	m
ρ	mass density of a particle	$kg\ m^{-3}$

5 General Principle

5.1 Particle size classification with the DEMC

The measurement of particle size distributions with a DMAS is based on particle classification by electrical mobility in a DEMC. The DEMC may be designed in many different ways; for example, coaxial cylindrical DEMC, radial DEMC, parallel plate DEMC, etc. The coaxial cylindrical DEMC shown in Figure 1 is an example of a widely used design. It consists of two coaxial, cylindrical electrodes with two inlets. One inlet (marked q_1 in Figure 1) is for filtered clean sheath air. The other inlet (marked q_2) is for the aerosol sample air.

The aerosol sample air, some of whose particles are electrically charged, enters the DEMC as a thin annular cylinder around a core of filtered, particle-free sheath air. By applying a voltage, an electric field is created between the inner and outer electrodes. A charged particle in the presence of an electric field will migrate within the field and reach a terminal migration velocity when the fluid dynamic drag on the particle balances the driving force of the electric field. Charged particles of the correct polarity within the sample air begin to drift across the sheath air flow towards the inner electrode. At the same time, the clean sheath air flow carries the charged airborne particles downward. A small fraction of the charged particles enters the thin circumferential slit near the bottom of the centre electrode and is carried by the air flow to the detector (in the direction marked q_3). By varying the voltage, particles of different electrical mobility are selected. The remaining (not extracted) air flow leaves the DEMC as excess flow (q_4).

The following terms are used for the flows entering and exiting the DEMC:

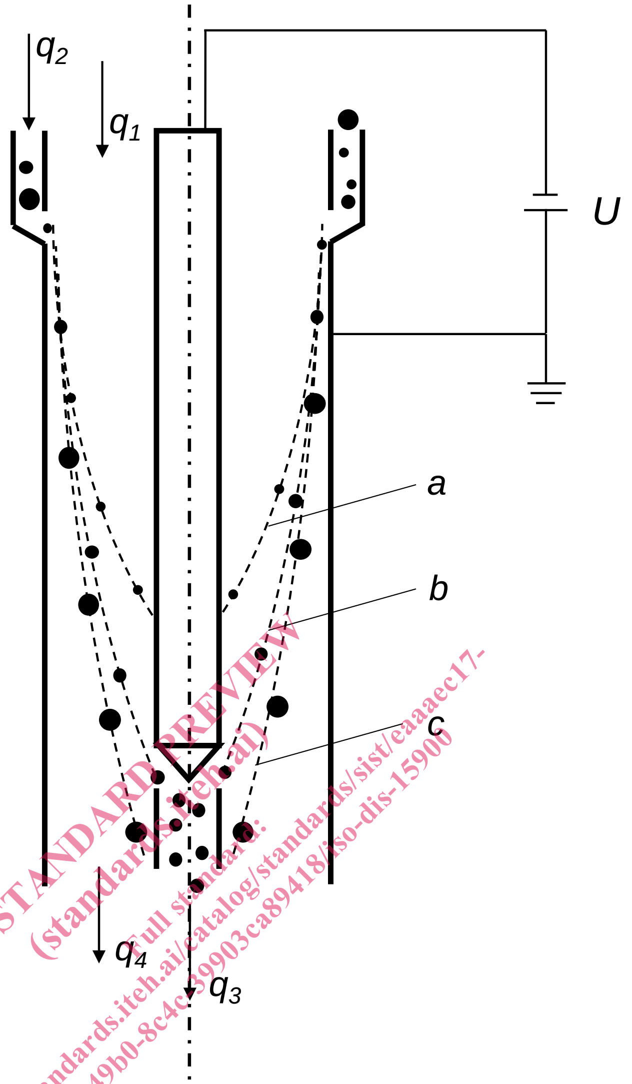
q_1 sheath flow

q_2 sample flow

q_3 monodisperse flow

q_4 excess flow

When used within a DMAS, measurements of relevant parameters such as voltage, flow and their timings need to be combined with other measurements such as the output from the particle detector. These parameters are usually controlled using a system controller as shown in Figure 3.



a Trajectory of particles trapped in the DEMC due to high electrical mobility

b Trajectory of particles leaving the DEMC with q_3

c Trajectory of particles trapped in the DEMC due to low electrical mobility

Figure 1 — Schematic diagram of coaxial cylindrical DEMC

5.2 Relationship between electrical mobility and particle size

The electrical mobility of a particle depends on its size and its electric charge. The relationship between electrical mobility and particle size for spherical particles can be described by Equation (1):

$$Z(d,p) = \frac{pe}{3\pi\mu_{\text{gas}}d} S_{\text{C}} \tag{1}$$

The slip correction, S_c, extends the Stokes' law-based calculation of the drag force on a spherical particle moving with low Reynolds number in a gas phase to nanometre-sized particles. It is approximated by the expression given in Equation (2):

$$S_{\text{C}} = 1 + Kn\left[A + B\exp\left(-\frac{C}{Kn}\right)\right] \tag{2}$$