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

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National foreword

This British Standard is the UK implementation of ISO 15900:2020. It supersedes BS ISO 15900:2009, which is withdrawn.

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INTERNATIONAL STANDARD

ISO 15900

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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

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Contents

Page

Foreword ... **v**
Introduction ... **vi**
1 Scope ... **1**
2 Normative references ... **1**
3 Terms and definitions ... **1**
4 Symbols ... **4**
5 General principle ... **5**
5.1 Particle size classification with the DEMC ... 5
5.2 Relationship between electrical mobility and particle size ... 6
5.3 Measurement and data inversion ... 7
5.4 Transfer function of the DEMC ... 8
5.5 Charge distribution function ... 9
5.5.1 General ... 9
5.5.2 Charge distribution function for radioactive bipolar charge conditioners ... 9
5.5.3 Charge distribution functions for other bipolar and unipolar charge conditioners ... 10
5.6 Particle losses in the DMAS ... 11
5.7 Effects due to non-spherical particles ... 11
5.8 Measurement of particle sizes below 10 nm ... 11
5.9 Traceability of measurement results ... 11
6 System and apparatus ... **13**
6.1 General configuration ... 13
6.2 Components ... 14
6.2.1 Pre-conditioner ... 14
6.2.2 Charge conditioner ... 14
6.2.3 DEMC ... 15
6.2.4 Aerosol particle detector ... 15
6.2.5 System controller, data acquisition and analysis ... 15
7 Measurement procedures ... **16**
7.1 Setup and preparation of the instrument ... 16
7.1.1 General ... 16
7.1.2 Aerosol pre-conditioning: Adapting the aerosol to be measured to the requirements of the DMAS ... 16
7.1.3 Aerosol pre-conditioning: Separation of large particles ... 16
7.1.4 Charge conditioning ... 17
7.1.5 DEMC: Flows ... 17
7.1.6 DEMC: Voltage ... 18
7.1.7 DEMC: Temperature and pressure ... 18
7.1.8 Particle detection: CPC ... 18
7.1.9 Particle detection: FCAE ... 18
7.1.10 Data acquisition ... 18
7.2 Pre-measurement checks ... 18
7.2.1 General ... 18
7.2.2 Overall DMAS check ... 19
7.2.3 Data acquisition check ... 19
7.3 Measurement ... 19
7.4 Maintenance ... 19
8 Periodic tests and calibrations ... **20**
8.1 Overview ... 20
8.2 Zero tests ... 21
8.2.1 General ... 21

AVA Documents
Document Sharing Hub

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Full document details: BS ISO 15900:2020

8.2.2 Particle detector zero test ... 21
8.2.3 Overall DMAS zero test with inlet filter ... 21
8.2.4 Overall DMAS zero test with DEMC voltage set to 0 V ... 21
8.3 Flow rate tests ... 21
8.4 Voltage calibration ... 22
8.5 Charge conditioner test ... 22
8.6 Calibration for size measurement ... 22
8.6.1 General ... 22
8.6.2 Purpose of calibration ... 22
8.6.3 Particle size standards ... 22
8.6.4 Dynamic DMAS particle size calibration procedure ... 23
8.6.5 Static DMAS particle size calibration procedure ... 24
8.7 Size resolution test ... 28
8.8 Number concentration calibration ... 28

9 Using a DEMC at a fixed voltage to generate particles of a chosen size ... 28
9.1 General ... 28
9.2 Multiply-charged particles ... 30
9.3 Size calibration with certified spheres ... 30
9.4 Sheath flow ... 30
9.5 Slip correction (if applicable) ... 30
9.6 Voltage (if applicable) ... 30
9.7 Calculation of overall uncertainty ... 31

10 Reporting of results ... 31

Annex A (informative) **Charge conditioners and charge distributions ... 32**

Annex B (informative) **Particle detectors ... 43**

Annex C (informative) **Slip correction factor ... 47**

Annex D (informative) **Data inversion ... 50**

Annex E (informative) **Cylindrical DEMC ... 66**

Annex F (informative) **Example certificate for a DMAS particle size calibration ... 71**

Annex G (informative) **Good practice for measurements at particle sizes below 10 nm ... 74**

Annex H (informative) **Examples for overall system tests ... 76**

Annex I (informative) **Comparison of different approaches to calculate diffusion loss in laminar tube flow ... 82**

Annex J (informative) **Corrections for effects due to non-spherical particles ... 86**

Bibliography ... 87

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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This document was prepared by Technical Committee ISO/TC 24, *Particle characterization including sieving*, Subcommittee 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:

— subclauses on particle losses due to Brownian diffusion, effects due to non-spherical particles, and measurement of particles below 10 nm have been added in Clause 5;

— traceability diagrams for DEMC and DMAS have been added in Clause 5;

— calibration for size measurement in Clause 8 has been refined;

— Clause 9 for “Using a DEMC at a fixed voltage to generate particles of a chosen size” has been added;

— Annex D for “Data inversion” has been rewritten completely;

— Annex F for “Example certificate for a DMAS particle size calibration” has been added;

— former Annex G for “Uncertainty” in the previous edition has been deleted;

— new Annex G for “Good practice for measurements at particle sizes below 10 nm” has been added;

— Annex H for “Examples for overall system tests” has been added;

— Annex I for “Comparison of different approaches to calculate diffusion loss in laminar tube flow” has been added;

— Annex J for “Corrections for effects due to non-spherical particles” has been added.

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.

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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 particle 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.

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INTERNATIONAL STANDARD **ISO 15900:2020**

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

1 Scope

This document provides guidelines and requirements for the determination of aerosol particle number 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 document 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 document, 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 document does not include technical requirements and specifications for the application of DMAS, which are defined in application specific standards or guidelines, e.g. for road vehicle applications (ISO/TC 22), environmental measurements (ISO/TC 146) or nanotechnologies (ISO/TC 229).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
aerosol
system of solid and/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 and 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

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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 to entry: The sizes of particles detected are usually smaller than several hundred nanometres and larger than a few nanometres.

Note 2 to entry: A CPC is one possible detector for use with a DEMC.

Note 3 to entry: 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* (3.11) 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 1 to entry: 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 able to select aerosol particles according to their electrical mobility and pass them to its exit

Note 1 to entry: 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 to entry: 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 1 to entry: Another common acronym for the DMAS is MPSS (mobility particle size spectrometer).

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3.13
electrical mobility
ratio of *migration velocity* (3.18) to electrical field for particles and ions in a gas

3.14
equivalent 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 1 to entry: Particle diameter (or simply diameter) used throughout this document 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.

3.15
Faraday cup aerosol electrometer
FCAE
electrometer designed for the measurement of electrical charge concentration carried by an aerosol

Note 1 to entry: 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. An FCAE measures electrical current ranging from about one femtoampere (fA) to about ten picoamperes (pA).

3.16
Knudsen number
Kn
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

3.17
laminar flow
gas flow with no temporally or spatially irregular activity or turbulent eddy flow

3.18
migration velocity
steady-state velocity of a charged airborne particle within an externally applied electric field

3.19
particle diameter
electrical mobility equivalent diameter

Note 1 to entry: Also, just called diameter.

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

[SOURCE: ISO 27891:2015, 3.27, modified — term “plateau efficiency” has been changed to "plateau detection efficiency.]

3.21
Reynolds number
Re
dimensionless number expressed as the ratio of the inertial force to the viscous force

Note 1 to entry: For example, applied to an aerosol particle or a tube carrying aerosol particles

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3.22
slip correction
S_C
dimensionless factor 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's drag
drag force acting on a particle that is moving relative to a continuum fluid in the creeping flow limit (low Reynolds number)

3.24
transfer function
ratio of particle concentration at the outlet of a DEMC to the particle concentration at the inlet of the DEMC

Note 1 to entry: It 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 apply.

Symbol	Quantity	SI Unit
A, B, C	elements of the slip correction factor defined in Formula (2)	dimensionless
c	thermal velocity of an ion or molecule	m s^{-1}
D	diffusion coefficient	m^2 s^{-1}
d	aerosol particle diameter	m
E	electric field strength in a DEMC	V m^{-1}
e	elementary charge = 1,602 176 634 × 10^{-19} C	
Kn	Knudsen number	(dimensionless)
k	Boltzmann constant = 1,380 649 × 10^{-23} 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_{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.	m^{-3}
N_A	Avogadro constant = 6,022 140 76 × 10^{23} mol^{-1}	
N_I	number concentration of ions	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	m^3 s^{-1}
Q_a	aerosol air flow rate	m^3 s^{-1}

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Symbol	Quantity	SI Unit
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
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	$m^2\ V^{-1}\ s^{-1}$
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
ε	relative error	
μ_{gas}	coefficient of dynamic viscosity of a gas	$kg\ m^{-1}\ s^{-1}$
λ	mean free path	m
ρ	mass density	$kg\ m^{-3}$

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 sample aerosol.

The sample aerosol, 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 aerosol 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).

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 5.

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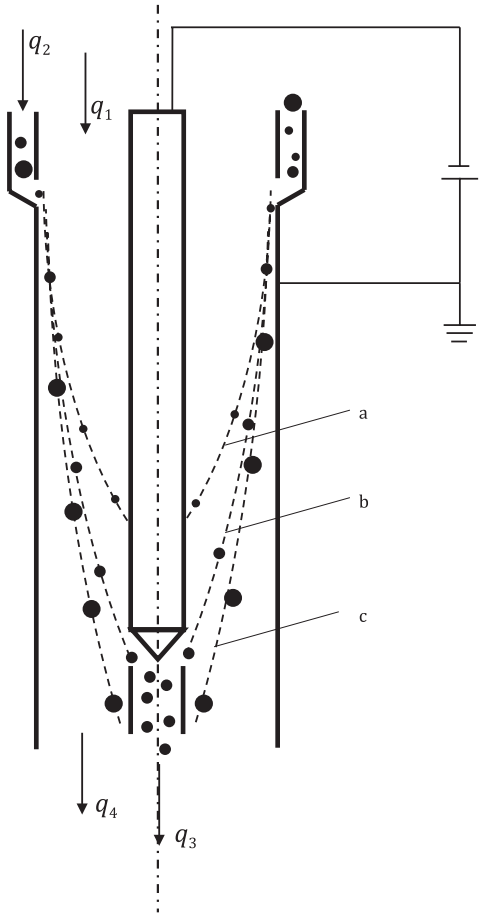

Key

q_1	sheath flow	a	Trajectory of particles trapped in the DEMC due to high electrical mobility.
q_2	sample aerosol flow	b	Trajectory of particles leaving the DEMC with q_3.
q_3	mobility selected aerosol flow	c	Trajectory of particles trapped in the DEMC due to low electrical mobility.
q_4	excess flow		

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 Formula (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's 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 Formula (2):

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

For a detailed discussion of the slip correction, see Annex C.

The dynamic viscosity and the mean free path of gas molecules used within Formulae (1) and (2), respectively, depend on both the temperature and the pressure of the carrier gas. Formulae (3) and (4)

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shall be used to calculate the viscosity and the mean free path for temperatures and pressures different from the reference temperature and pressure, T_0 and P_0, specified in Table 1, respectively.

$$\mu_{\text{gas}} = \mu_{\text{gas},0} \cdot \left(\frac{T}{T_0}\right)^{\frac{3}{2}} \cdot \left(\frac{T_0 + S}{T + S}\right) \tag{3}$$

$$\lambda = \lambda_0 \cdot \left(\frac{T}{T_0}\right)^{2} \cdot \left(\frac{P_0}{P}\right) \cdot \left(\frac{T_0 + S}{T + S}\right) \tag{4}$$

where S, the Sutherland constant, has the value given in Table 1.

Unless explicitly specified differently in the measurement report, Formulae (1) to (4) and the set of parameters given in Table 1 shall be used for the calculation of the relation between electrical mobility and particle size in air.

Table 1 — Values of parameters for the calculation of the electrical mobility from the particle size in dry air at T_0 = 296,15 K and P_0 = 101,3 kPa [33]

Parameter	Value
$\mu_{\text{gas},0}$	1,832 45 × 10^{-5} kg m^{-1} s^{-1}
λ_0	6,730 × 10^{-8} m
S	110,4 K
A	1,165
B	0,483
C	0,997

5.3 Measurement and data inversion

For a given supply voltage, U, the response, $R(U)$, of the particle detector to aerosol particles entering the DEMC is given by Formula (5), which is called the basic equation for the response of the electrical mobility measurement:

$$R(U) = q_2 \sum_{p=1}^{\infty} \int_{d=0}^{\infty} n(d) \cdot P(d) \cdot f_p(d) \cdot \Omega(Z(d,p), \Delta\Phi(U)) \cdot W(d,p) \mathrm{d}d \tag{5}$$

For condensation particle counters (CPCs), the response is particle number concentration, while it is charge concentration for Faraday cup aerosol electrometers (FCAEs).

$W(d, p)$ describes the detector response;

For CPCs, $W(d, p) = \eta_{\text{CPC}}(d)\, q_{\text{CPC}-1}$, where $\eta_{\text{CPC}}(d)$ is the size-dependent detection efficiency of the CPC and q_{CPC} is the detection flow of the CPC.

For FCAEs, $W(d, p) = p\, e\, \eta_{\text{FCAE}}(d)\, q_{\text{FCAE}-1}$, where p is the number of elementary charges on a particle, e is the elementary charge, $\eta_{\text{FCAE}}(d)$ is the size-dependent detection efficiency of the FCAE, and q_{FCAE} is the detection flow of the FCAE.

$n(d)\,\mathrm{d}d$ is the number concentration of aerosol particles in the diameter interval dd around d;

$P(d)$ is the penetration which accounts for diffusion losses (see 5.6 and Annex I).

$f_p(d)$ is the charge distribution function (see 5.5 and Annex A);

$\Omega[Z(d,p), \Delta\Phi(U)]$ is the transfer function of the DEMC (see 5.4 and Annex E), which uses the functions $Z(d, p)$ and $\Delta\Phi(U)$ below as arguments;

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$Z(d, p)$ is the electrical mobility of a particle with diameter d carrying p elementary charges (see 5.2);

$\Delta\Phi(U)$ is a function of the supply voltage and the geometry of the DEMC (see 5.4 and Annex E). For a cylindrical DEMC, $\Delta\Phi(U)$ is given in Formula (E.2).

If the transfer function, Ω, the charge distribution function, $f_p(d)$, and the maximum particle size (see 6.2.1) are known, the particle size distributions can be calculated based on the measurements with a DEMC. An example calculation is given in Annex D.

NOTE 1 Formula (5) applies to the case when the DEMC classifies positively-charged particles, since the range of the summation is from $p = +1$ to $+\infty$. For the mode of classifying negatively-charged particles, the range is from $p = -1$ to $-\infty$.

NOTE 2 A DEMC can be (electrically) described as a capacitor. $\Delta\Phi(U)$ can then be linked to the DEMC's capacitance, C_E, where $\Delta\Phi(U) = U \cdot C_E/(2 \cdot \pi \cdot \varepsilon_0)$, $\varepsilon_0 = 8{,}854 \times 10^{-12}$ F m^{-1}.

5.4 Transfer function of the DEMC

The transfer function, Ω, of a DEMC is defined as the probability that an aerosol particle which enters the DEMC at the aerosol inlet will leave via the detector outlet. It can, mathematically, easily be described in the mobility regime. Therefore, this approach is taken here. The transfer function depends on the particle's electrical mobility, Z, on the four volumetric flow rates, on the geometry of the DEMC and on the electrical field strength. The influence of the geometry and the electrical field strength on the transfer function is expressed by $\Delta\Phi$, which is a function of the geometry and the variable supply voltage, U, of the DEMC. For a given supply voltage, $\Delta\Phi$ is constant.

If particle inertia, gravimetric sedimentation, Brownian motion, space charge and its image forces are neglected, and if the sheath flow in the DEMC is recirculated ($q_1 = q_4$, also resulting in $q_2 = q_3$), the transfer function of a DEMC can be described as an isosceles triangle with the half-width, ΔZ, centred around the electrical mobility, Z^*, as in Figure 2.

When particle diffusion due to Brownian motion is significant, the resolution of the DEMC classification is reduced, which corresponds to a broader and shorter transfer function.

A detailed discussion of the transfer function for the example of a coaxial cylindrical DEMC can be found in Annex E.

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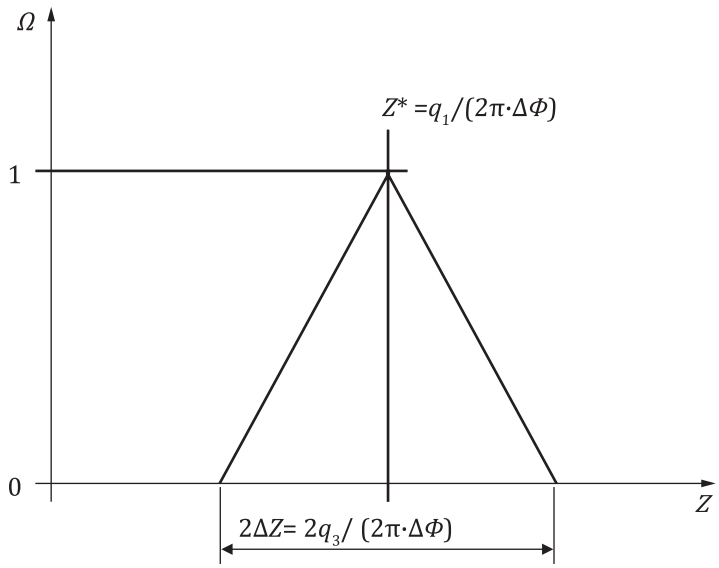

Key

Z	electrical mobility	Z^*	centre electrical mobility of the transfer function
Ω	transfer function	ΔZ	half-width of the transfer function

Figure 2 — Transfer function of a DEMC with sheath flow re-circulation ($q_1 = q_4$ and $q_2 = q_3$)

5.5 Charge distribution function

5.5.1 General

As stated in 5.3, the particle size-dependent charge distribution function, $f_p(d)$, shall be explicitly known to calculate the size distribution of airborne particles classified in a DEMC. A charge conditioner is used at the entrance of a DEMC to achieve a conditioned charge distribution which is independent of the initial charge state of the aerosol particles and which is - at least for typical aerosol residence times in a DEMC - in a steady-state or stable. $f_p(d)$ may then be given by a set of formulae or tabulated data, approximating the size-dependent charge distribution by theoretical models and/or empirical data.

There are several types of bipolar or unipolar charge conditioners which are described in more detail in 5.5.2. Bipolar charge conditioners produce positively and negatively charged particles while unipolar charge conditioners produce particles of one polarity (positive or negative) only.

5.5.2 Charge distribution function for radioactive bipolar charge conditioners

For commercially available radioactive bipolar charge conditioners the charge distribution function under standard conditions (spherical particles in air (293,15 K, 101,3 kPa) is given by Formula (6) in combination with the coefficients given in Table 2 and Formula (7) which are derived from an approximation (Wiedensohler (1988) [50] to theoretical models in combination with a result from Gunn (1956) [24]).

$$\log\left[f_p(d)\right] = \sum_{i=0}^{5} a_i(p)\cdot(\log d)^i \tag{6}$$

NOTE 1 In Formula (6), d is given in nanometres.

Formula (6) is valid for the size range:

1 nm ≤ d ≤ 1 000 nm for p = {-2, −1, 0, +1, +2}

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Table 2 — Coefficients $a_i(p)$ for Formula (6) for radioactive ion sources

i	$a_i(p)$				
	$p = -2$	$p = -1$	$p = 0$	$p = +1$	$p = +2$
0	−26,332 8	−2,319 7	−0,000 3	−2,348 4	−44,475 6
1	35,904 4	0,617 5	−0,101 4	0,604 4	79,377 2
2	−21,460 8	0,620 1	0,307 3	0,480 0	−62,890 0
3	7,086 7	−0,110 5	−0,337 2	0,001 3	26,449 2
4	−1,308 8	−0,126 0	0,102 3	−0,155 3	−5,748 0
5	0,105 1	0,029 7	−0,010 5	0,032 0	0,504 9

The charge distribution function, $f_p(d)$, with three or more elementary charge units can be calculated using the following Formula (7), which is based on Gunn's model:

$$f_p(d) = \frac{e}{\sqrt{4\pi^2 \varepsilon_0 dkT}} \cdot \exp \frac{-\left[p - \frac{2\pi\varepsilon_0 dkT}{e^2} \cdot \ln\left(\frac{N_I^+}{N_I^-} \cdot \frac{Z_I^+}{Z_I^-}\right)\right]^2}{2\frac{2\pi\varepsilon_0 dkT}{e^2}} \tag{7}$$

where $N_I^{\pm}$ is the concentration of positive or negative small ions.

For this calculation, the concentration of positive and negative ions is assumed to be equal, and the ratio of ion mobilities Z_I^+ / Z_I^- was taken from Wiedensohler (1988) to be 0,875. Results of this calculation are given in Table 3 and in Figure A.1.

NOTE 2 Two coefficients in Wiedensohler (1988) were later corrected. The coefficients in Table 2 contain this correction.

Table 3 — Bipolar charge distribution function $f_p(d)$ for spherical particles in air (293,15 K, 101,3 kPa), produced by radioactive charge conditioners; see Formulae (6) and (7)

d	**Charge distribution function**												
(nm)	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6
1	0	0	0	0	0	0,004 8	0,999 3	0,004 5	0	0	0	0	0
2	0	0	0	0	0	0,008 3	0,974 2	0,007 5	0	0	0	0	0
5	0	0	0	0	0	0,022 5	0,969 3	0,018 9	0	0	0	0	0
10	0	0	0	0	0	0,051 4	0,912 4	0,041 1	0	0	0	0	0
20	0	0	0	0	0,000 2	0,109 6	0,793 1	0,084 6	0,000 1	0	0	0	0
50	0	0	0	0	0,011 4	0,222 9	0,581 4	0,169 6	0,006 6	0	0	0	0
100	0	0	0,000 1	0,003 7	0,056 1	0,279 3	0,425 9	0,213 8	0,031 7	0,001 7	0	0	0
200	0	0,000 5	0,005 3	0,034 0	0,121 1	0,264 1	0,299 1	0,204 3	0,071 9	0,015 3	0,001 8	0,000 1	0
500	0,006 7	0,020 7	0,050 4	0,098 0	0,149 0	0,181 6	0,181 8	0,140 3	0,089 1	0,044 0	0,017 3	0,005 4	0,001 4
1 000	0,035 7	0,058 4	0,085 4	0,111 3	0,126 1	0,138 5	0,123 5	0,103 9	0,075 4	0,050 0	0,029 3	0,015 4	0,007 2

5.5.3 Charge distribution functions for other bipolar and unipolar charge conditioners

Calculations of the respective charge distribution functions for non-radioactive bipolar and unipolar charge conditioners are complicated and require careful experimental verification before usage in data inversion routines for the analysis of measured data. The theoretical concepts described in Annex A may be helpful for the experienced user to calculate a charge distribution function for a given charge conditioner. Annex A also shows an example for the charge distribution function for a charge conditioner based on an X-ray ionization source.

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5.6 Particle losses in the DMAS

When aerosol particles collide with a surface, they adhere due to van der Waals force, electrostatic force and surface tension. Particles transported to any inner surface (e.g. tubing) of the DMAS – besides those transported to the electrodes of the DEMC forced by the electrical field - do not reach the particle detector; they are lost. Such losses can be caused by diffusional and electrostatic effects. Inertial transport and deposition are not significant in a DMAS because of the particle size range. Since the air flow in nearly all parts of the DMAS is laminar and the particles are small, the dominant transport mechanism for the particles is Brownian diffusion. The smaller the particle the more rapid their diffusion (Einstein, 1905) and the higher their losses. Hence, the measured size distribution will under-represent small particles. Diffusion losses in the DMAS should be estimated and corrected.

Three sets of equations for diffusion losses in straight tubes [Gormley and Kennedy (1949) [59], Hinds (1999) [60] and Willeke and Baron (1993) [68]], which give very similar results, can be found in literature; they all quantify the penetration P_{Tube} through a straight tube (i.e. the ratio between the particle concentration leaving the tube and entering the tube) with laminar flow.

The formulae to calculate the diffusion loss can be found in Annex I, which also contains a comparison between the three approaches.

5.7 Effects due to non-spherical particles

In a DEMC, particles are classified according to their electrical mobility. For spherical particles, Formulae (1) and (2) in 5.2 are sufficient to relate a particle's electrical mobility to its diameter. For non-spherical particles, introducing the mobility equivalent diameter overcomes the complex problem of otherwise necessary corrections for Formulae (1) and (2). In addition, the charge distribution for non-spherical particles can differ from the charge distribution for spherical particles (see 5.5).

All published approaches for the correction of the effects of non-spherical particles require knowledge about the particle shape; they can therefore be used only in special cases. An example for a correction is shown in Annex J.

5.8 Measurement of particle sizes below 10 nm

Measurement uncertainties increase as particle sizes decrease from 10 nm towards 1 nm. Good measurement practice given in Annex G should be followed to achieve acceptable quality when measuring in the below 10 nm size range.

5.9 Traceability of measurement results

Figures 3 and 4 illustrate the metrological traceability chains for quantities that are influential to results of measurements by a DMAS.

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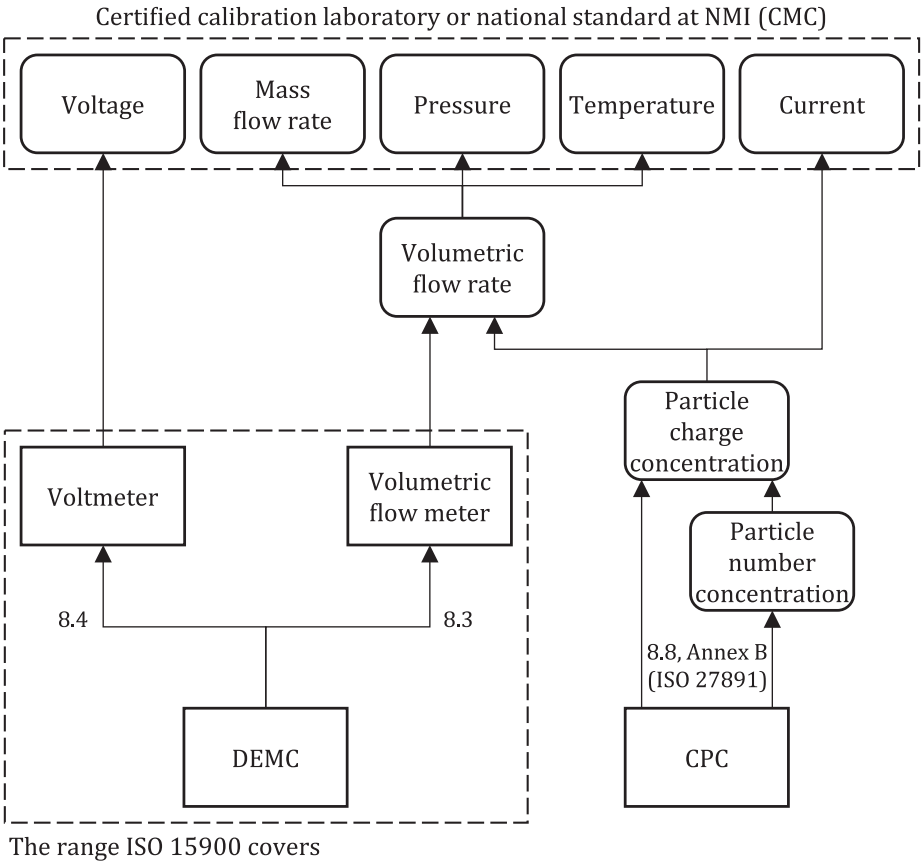

Figure 3 — Traceability diagram for DEMC and CPC with references to subclauses in Clause 8

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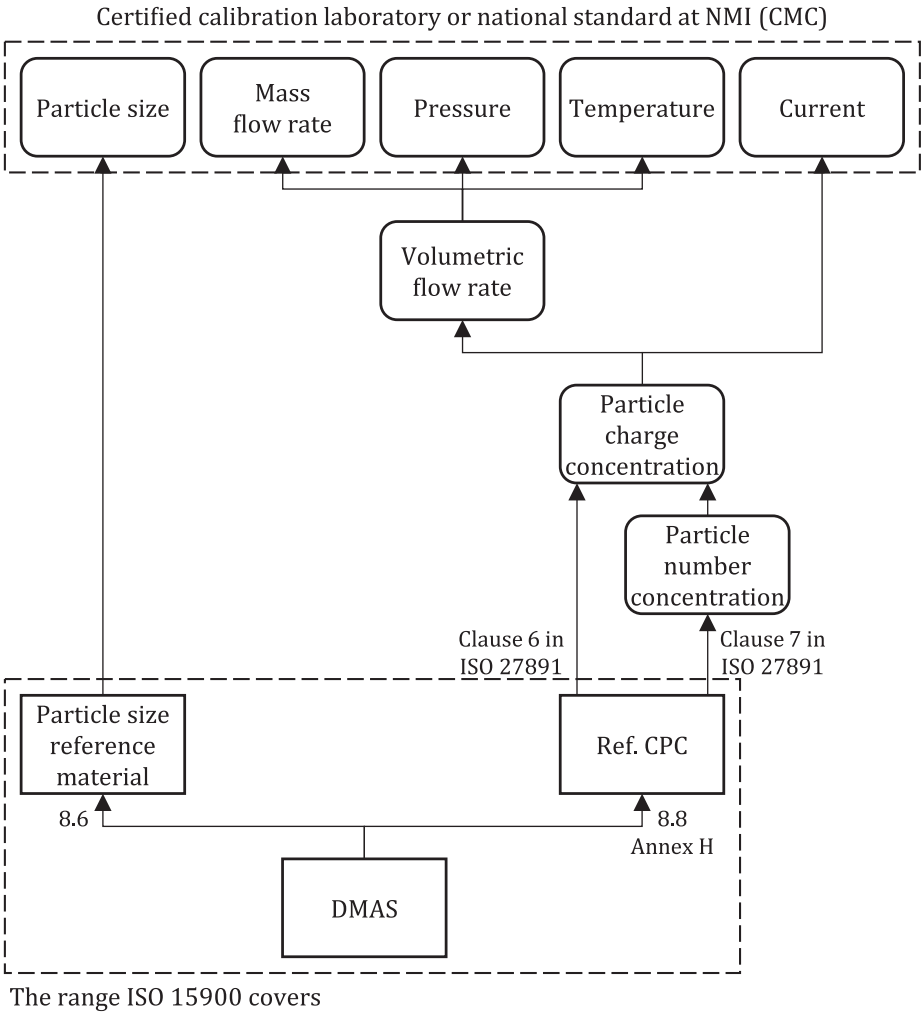

Figure 4 — Traceability diagram for DMAS with references to subclauses in Clause 8

6 System and apparatus

6.1 General configuration

A complete DMAS for the measurement of particle size distributions based on differential electrical mobility analysis typically has the following fundamental components (see Figure 5):

a) pre-conditioner;

b) charge conditioner;

c) DEMC with flow control and high voltage control;

d) aerosol particle detector;

e) system controller with data acquisition and data analysis (typically built-in firmware or dedicated software on a personal computer).

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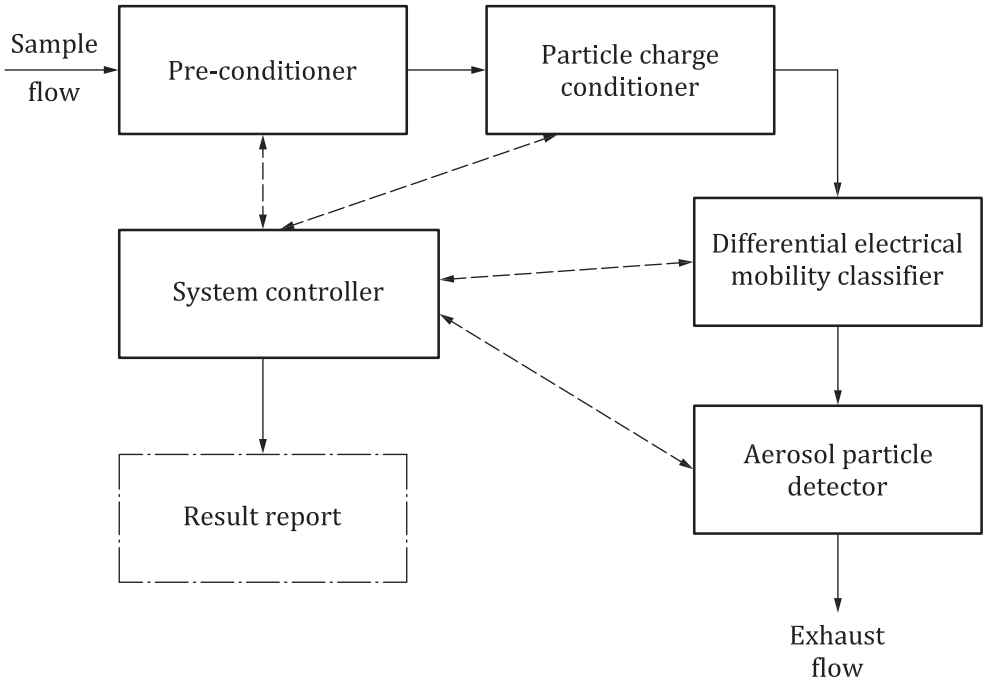

Figure 5 — Fundamental components of the differential mobility analysing system (DMAS)

Differential electrical mobility analysis is typically used for airborne particles ranging from a few nanometres to approximately one micrometre. Aerosol samples can be measured from a variety of sources. The most common sample sources are particles aerosolized from a liquid suspension, particles sampled directly from the atmosphere and particles sampled from a combustion source. The particle pre-conditioner and the charge conditioner are necessary to achieve defined sample conditions.

Most DMASs separate a mono-mobile fraction of the aerosol flow, which is transferred to the aerosol particle detector for particle number concentration measurement. In addition to the basic system configuration shown in Figure 5, other configurations exist, for example, systems with two parallel DEMCs and detectors for extended particle size range, systems with multiple detectors or systems with multiple parallel DEMCs and detectors.

The entire measurement is controlled by the system controller, which also acquires data and performs data inversion. The system control can, for example, reside as software and/or hardware in a personal computer. It can also be integrated into a self-contained particle sizing instrument.

6.2 Components

6.2.1 Pre-conditioner

The pre-conditioner component serves two purposes: removing large particles and, if necessary, reducing the sample humidity. Other pre-conditioning may be required for specific applications.

NOTE Calibrating the differential pressure across the particle pre-conditioner against the flow rate through this device is a helpful sample aerosol flow measurement which does not interfere with the incoming particles.

6.2.2 Charge conditioner

In order to calculate the particle number distribution from the measured electrical mobility number distribution, a known particle size-dependent distribution of electrical charges shall be generated on the aerosol particles. Charge conditioners upstream of a DEMC are used for this purpose. The charge distribution is the result of the random thermal diffusion (Brownian motion) of the ions which leads to frequent collisions with the particles and the attachment of ions on particles. The particle concentration to be charged shall be limited in such a way that the depletion of ions due to ion attachment to the

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particles does not lead to significantly reduced charges on the particles. The particle charging depends mainly on the so-called $N_I \cdot t$ product, which is the concentration of either positive or negative ions, N_I, multiplied by the typical interaction time, t, of aerosol particles with the ions. In some charge conditioner designs the ion transport is purposely influenced by AC- or DC-electric fields and sheath air flows.

Unipolar charging can yield a higher $N_I \cdot t$ product than bipolar charging, thus increasing the transmission efficiency of a DMAS by increasing the number of charged particles. The increased $N_I \cdot t$ product, however, leads to both a higher fraction of multiply-charged particles and higher charge levels on these particles. This has the adverse effect of reducing the size resolution of the DEMC. Therefore, unipolar charging is typically used for instruments with lower size resolution or when the size range being measured is limited such that multiple charges remain insignificant.

A.3 gives an overview on charge conditioners.

6.2.3 DEMC

The DEMC is the core component of a DMAS. The basic operating principle is electrical mobility discrimination by particle migration perpendicular to a laminar sheath flow. The migration is determined by an external electrical force and the counteracting particle drag forces in the laminar sheath flow.

DEMC can be designed in a variety of geometries. The classifying characteristic of a DEMC is described by its transfer function. Whatever the geometrical design of the DEMC, the transfer function is defined by the critical mobilities, which are determined by the geometrical dimensions of the device, by the flow rates and by the voltage potential between the electrodes. Details on the transfer function of the DEMC can be found in 5.4. For the example of a coaxial cylindrical DEMC, details on the critical mobilities as well as the transfer function can be found in Annex E.

Measuring a particle size distribution is usually achieved by changing the voltage. For transient measurements, DMASs with multiple particle detectors have been designed. These systems typically operate with fixed voltages.

6.2.4 Aerosol particle detector

The aerosol outlet from the DEMC shall be connected to a well-characterized particle detector. This instrument shall be able to detect particles exiting the DEMC with known efficiency across the entire size range to be reported. The lower end of the size range limits the aerosol particle detector that can be used. In general, either a continuous flow condensation particle counter (CPC) or an aerosol electrometer is used.

In a CPC, aerosol particles are exposed to condensable supersaturated vapour. Vapour condensing on the particles grows them into droplets that can be counted by optical means.

Aerosol electrometers are typically designed as Faraday cup aerosol electrometers (FCAEs). The aerosol particles deposit on a filter inside the Faraday cup. The electrical charge on the deposited particles can be measured as a current by the electrometer amplifier.

These two, most common aerosol particle detectors are discussed further in Annex B.

6.2.5 System controller, data acquisition and analysis

The system controller with data acquisition and data inversion should cover several tasks. Before the measurement, the system control of an automated measuring system should set all operating parameters and flag the operator if any of these parameters cannot be set correctly. During the measurement, the system control should acquire and monitor all critical parameters (for example, the flow rates) and flag a warning to the operator if any of these parameters are outside pre-established tolerances. At the same time, the control system should set the electrode voltage through the variable high voltage supply and read the particle number data from the aerosol particle detector. Either during or after the measurement, data inversion takes place and the measured particle size distribution is presented, stored, exported, etc.

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The system control should also create an event log which contains all detected irregularities during a measurement.

7 Measurement procedures

7.1 Setup and preparation of the instrument

7.1.1 General

Proper instrument setup is critical in obtaining the correct particle size distribution. There are many different ways to configure and operate a DMAS instrument and the reader shall refer to the manufacturer's instrument manuals for specific details. This clause addresses only those issues common to all types of DMAS systems.

7.1.2 Aerosol pre-conditioning: Adapting the aerosol to be measured to the requirements of the DMAS

7.1.2.1 Particle concentration

The particle concentration in the aerosol entering the DMAS may not exceed the upper limit of the operating range of the system. If not, dilution is required to reduce the particle concentration. ISO 27891:2015, Annex F contains a description of diluters.

7.1.2.2 Temperature and pressure

Temperature and pressure of the aerosol entering the DMAS shall be within the operating range of the system. If not, temperature conditioning as well as pressure adaption are necessary. Whenever possible, such conditioning should be made with neglectable (or at least minimized) effect on the particle properties.

7.1.2.3 Humidity

A DMAS requires non-condensing conditions for reliable operation. If the risk of condensation within the system exists, drying is required.

For atmospheric sampling, humidity may or may not play a role in obtaining an accurate particle size distribution. However, it shall be considered when making a measurement. Hygroscopic particles (e.g. sulfate particles) can change size depending on the amount of water in the air. Other types of particles (e.g. elemental carbon) will not be appreciably affected by humidity. Since humidity can change over time, the size distribution of the sample aerosol can also change over time. If sampling times are sufficiently long, the aerosol size distribution can change during a single measurement. This can be avoided by pre-drying the incoming aerosol with a membrane or diffusion dryer or by using dry dilution air to lower the relative humidity to less than 40 %. Other humidity control devices can allow measurements to be made at a constant relative humidity. In any case, it is important to consider how humidity may affect atmospheric aerosol measurements and how a dryer may affect particle losses.

Particles obtained through atomization shall be thoroughly dried in order to obtain an accurate particle size distribution. Dilution air is preferable if the aerosol concentration is very high and can tolerate dilution. If that is not the case, a membrane or diffusion dryer is the best choice.

7.1.3 Aerosol pre-conditioning: Separation of large particles

Measuring particle size distributions with a DMAS requires data inversion, as described in 5.3 and Annex D. In order to solve the inversion equations, it is necessary to know the size of the largest particles allowed to enter the DEMC. This will prevent larger multiply-charged particles from entering the DEMC. Large particles carrying multiple charges may have the same electrical mobility as

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smaller, singly-charged particles. By removing the larger particles, the true size distribution is more accurately determined.

A pre-separator with known cut-off sizes shall be installed in the sample aerosol flow to fulfil this need. Commonly used pre-separators are impactors or cyclones. The cut-off size and steepness of the cut-off curve should be selected such that

a) the pre-separator does not remove particles from the desired size range of the measurement, and

b) the cut-off size is within the size range for data inversion.

NOTE Impactors are mostly used for sample aerosol flow rates of less than 1,5 l/min; cyclones are applicable for sample aerosol flow rates of 1 l/min and more.

During operation, some particles will deposit in the pre-separator. Therefore, the pre-separator needs to be regularly inspected and cleaned when necessary.

7.1.4 Charge conditioning

All aerosol samples shall be charge conditioned in a defined and reproducible way just before entering the DEMC. See Annex A for an overview on charge conditioners and for more details.

It is important to ensure proper performance of the charge conditioner, especially at a high incoming particle concentration. An improperly working charge conditioner will skew the particle size distribution, giving incorrect results.

7.1.5 DEMC: Flows

The flow control system is an important component with respect to the precision, resolution and repeatability of a DEMC. Both the particle sizing and the particle concentration measurement rely on accurately known flows.

Depending on the type of DEMC used, the sheath flow to sample aerosol flow ratio will vary. A high sheath/sample aerosol flow ratio will result in a narrow transfer function with better resolution of the size distribution. A higher sheath flow rate also reduces diffusion broadening within the DEMC. A low sheath/sample aerosol flow ratio will increase the aerosol concentration, desirable for lower concentration aerosols.

Every DEMC has two flows entering the device (sample aerosol flow and sheath flow) and two flows exiting the device (mobility selected aerosol flow and excess flow). Three out of these four flows shall be controlled for stable operation. The sheath air shall be particle free. In order to avoid interference with the aerosol to be measured, the recommended flows to be controlled are the recirculating excess/sheath flow and the mobility selected aerosol flow. Absolute accuracy on the flow rate measurements is critical since the sample aerosol flow is, in general, determined by the difference between the outgoing flows and the incoming sheath flow.

The inlet and outlet flows are strongly coupled, so upstream or downstream perturbations to any one of the flows may cause other flows to change. To minimize the sensitivity to such perturbations, the flow network should be carefully designed. The volumetric flow rates shall be defined and kept constant during the measurement. It should be periodically ensured that there are no leaks in the system.

The flow control system can be simplified and stabilized by cleaning and recirculation of the excess flow as sheath flow in a closed loop. This recirculation not only guarantees that the sheath flow equals the excess flow, it also eases the constraints on the precision with which the sheath and excess flow rates are measured since, in steady-state operation, the incoming sample aerosol flow exactly equals the outgoing mobility selected aerosol flow, provided there are no leaks in the recirculation system and the temperature of the recycled particle-free gas is the same as that of the incoming aerosol flow into the DEMC. An exception is a measuring setup where the aerosol inlet is pressurized (overpressure sampling mode). In such a case, it might become necessary to use a metered bleed to allow balancing of the flows.

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7.1.6 DEMC: Voltage

In most DMAS systems, a variable DC high-voltage supply is used to control the potential difference between the DEMC's electrodes. Fluctuations in the voltage across the DEMC will greatly affect the resulting particle size distribution measurement. On the low voltage range, any uncorrected offset of the power supply influences the sizing accuracy for high mobility particles.

For large, low-mobility particles, the required voltage can be high, reaching up to 10 kV to 12 kV. The maximum voltage should be limited in order to prevent arcing within the instrument. Arcing generates artefact particles and can damage exposed surfaces in the instrument. The stability of the supplied voltage influences the resolution and repeatability of the DEMC.

For safety reasons, the outer DEMC surfaces are normally grounded while the variable, positive or negative voltage supply is connected to an inner electrode.

7.1.7 DEMC: Temperature and pressure

The temperature and pressure inside the DEMC should be monitored during the measurement. Temperature and pressure fluctuations will adversely affect the data inversion unless they are taken into account.

7.1.8 Particle detection: CPC

Typically, a CPC has effectively 100 % detection efficiency over a wide range of particle sizes. Toward the low end of the detectable size range, the detection efficiency decreases to zero with a relatively steep sensitivity curve.

If the measuring range of the differential mobility analysing system extends into the range of the decreasing efficiency curve of the CPC, the measurements shall be corrected accordingly.

A CPC shall be operated within its specified particle concentration range. If the particle concentration is higher than the upper limit of the specified concentration range, particle coincidence will become significant and therefore will cause erroneous measurements.

7.1.9 Particle detection: FCAE

If an FCAE is used as a particle detector, the particle concentration exiting the DEMC shall provide an electrical current well above the noise level of the electrometer. Currently, aerosol electrometers measure electrical currents down to approximately 1 fA (or approximately 6 250 singly-charged particles per second).

7.1.10 Data acquisition

Most commercially available instruments have data acquisition software. It is important to make sure that the software collects all of the necessary data during the measurement. This will include the particle counts (from the particle counter) or electrical current (from the electrometer), the DEMC voltage, all necessary flow rates, temperature, pressure, etc. Some software packages have more options than others. Refer to the instrument manufacturer's manuals for details on setting up the data acquisition system.

7.2 Pre-measurement checks

7.2.1 General

There are several tests that can be made to ensure that the entire system is operating properly. These tests are also helpful in instrument troubleshooting.

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7.2.2 Overall DMAS check

Apply clean air (through a HEPA filter) to the DMAS inlet and run a size distribution measurement. There should be no (or only very few) particles detected across the whole particle size distribution. Remove the filter to expose the DMAS to normal, non-filtered air and run another size distribution measurement. Check if a significantly larger number of particles are observed in the size distribution compared to that of filtered air.

7.2.3 Data acquisition check

Ensure that the data acquisition system is connected and operating properly. Verify that the voltages, particle counts, flow rates and other necessary data are recorded.

7.3 Measurement

Once the instrument has been set up and checked, measurement can begin. The parameters of the measurement will depend on the type of DMAS system used and the type of aerosol being measured. In all cases, determination of the particle size distribution requires measuring the number concentration of all particles exiting the DEMC at a given voltage. These have the same electrical mobility but can have different sizes due to possible multiple charges. Repeated measurements of the particle concentration at different voltages will provide a concentration versus electrical mobility curve that is the basis for determining the size distribution.

There are many different ways to run a DMAS. It is up to the operator to decide on the best method based on the measurements to be made, the equipment used and the instrument manufacturer's recommendations.

For the measurement, a few considerations should be noted.

a) A stepping DMAS system changes the voltage between concentration measurements. For a stepping system, it is important to allow enough time for the particle detector to achieve a steady-state concentration. The amount of time needed for each step can be approximated by determining the travel time of the aerosol from the DEMC inlet to the particle detector based on the operating flow rate and tube length. Some commercial software packages can reduce the time needed between voltage steps by the use of proprietary algorithms. However, manual scans and manual adjustments will usually need longer times at each voltage.

b) A scanning DMAS system smoothly changes the voltage (often as an exponential ramp) during a continuous measurement of the particle concentration. The scanning direction “upscan” designates a scan from a low voltage to a high voltage. The inverse is called “downscan”. For a scanning system, the time constants (residence time of the particle in the DEMC, residence time in the tubing between DEMC and particle detector, the response time of the particle detector and the time constant for the voltage ramp) and the scanning direction may cause a shift and a deformation of the transfer function compared with the stepping system (Collins et al., 2004, [12]).

c) It is important to know the stability of the source. Rapid changes of the size distribution, the particle concentration, or both, affect the measurement of the size distribution. Critical conditions of the particle source can be identified by repeating the size distribution measurement and by changing the measuring procedure (number of voltage steps, scan time).

The periodic tests and calibrations required during measurement are set out in Clause 8.

7.4 Maintenance

The maintenance schedule for a DMAS depends highly on the application, including aerosol type and aerosol concentration. The interval for maintenance depends on the sampled aerosol concentration and frequency of use. The following parts of a DMAS should be regularly cleaned:

Pre-separator: Pre-separator (e.g. impactors or cyclones) surfaces which get in contact with sampled aerosol should be cleaned with compressed air or an ultrasonic bath. Particles collected on the pre-

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separator surfaces should be removed. Impactor plates should be recoated with a thin layer of vacuum grease. The maintenance should be done every six hours of sampling unless experience has proven that longer sampling times between cleanings may be tolerated.

Charge conditioner: Charge conditioners should be checked to ensure operation as expected; e.g. the radiation source of radioactive charge conditioners has not exceeded its useful lifetime. Cleaning charge conditioners can be hazardous and should only be performed by a trained professional. The cleaning or repair of radioactive sources by the end-user is not recommended. Local radiation protection laws, regulations, guidelines etc. can apply when using these devices, (see A.2.2.5).

Electrodes: DEMC electrodes should be cleaned after every few months of continuous sampling. Use a very soft tissue to clean all electrode surfaces. Some particles on the electrodes will have no effect on the performance of the DEMC, but layers of particles could cause flow disturbances and could distort the electrical field. After cleaning, the surfaces of the DEMC electrodes should be checked visually for any damage. Even small scratches could lead to flow disturbances or change the electrical field, causing turbulence and resulting in an inaccurate transfer function for the DEMC.

Other internal components: During operation, many components are exposed to solid or liquid particle deposition. All components that are exposed to such deposition shall be cleaned regularly. Excessive soiling may change the geometry and particle cut-size of the pre-conditioner, may reduce the efficiency of the charge conditioner, may distort the electric field and/or the laminar flow in the DEMC and may affect the accuracy of the particle detector.

Filters for sheath air/excess air: Most of the aerosol particles entering a DEMC will not be classified and will exit with the excess flow and deposit on a clean-air filter. The filter shall be replaced when necessary to avoid creating a large pressure drop within the sheath flow, which is normally obtained from recirculation of the excess flow.

8 Periodic tests and calibrations

8.1 Overview

Following the procedures in 8.2 to 8.8 ensures that a DMAS attains a known, small uncertainty for measurement of particle size and concentration. These procedures shall be performed only by qualified personnel. The procedures shall cover the fundamental components as summarized in the matrix in Table 4. Test and calibration procedures are also described, e.g. in Wiedensohler et al. (2018) [75].

Table 4 — Matrix for sensitive components of a DMAS

	Charge conditioner	DEMC	Aerosol particle detector	System controller	Entire DMAS
Zero tests (8.2)			X		X
Flow rate tests (8.3)		X	X	X	X
Voltage calibration (8.4)		X		X	
Charge conditioner test (8.5)	X			X	X
Calibration for size measurement (8.6)				X	X
Size resolution test (8.7)				X	X
Number concentration calibration (8.8)			X	X	X

NOTE The pre-conditioner is not listed in this table since it requires only the maintenance in 7.4 and does not require periodic tests and calibrations.

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8.2 Zero tests

8.2.1 General

Once the flow rates are checked, there are three zero tests that can be performed to ensure that there are no leaks and that the instruments are working properly.

A CPC should be used as particle detector for the zero tests.

If one of these three tests fails, additional leakage test of the components and eventually service to repair a leak in the DMAS may become necessary.

8.2.2 Particle detector zero test

Disconnect the particle detector from the DEMC and keep the tubing exposed to normal office or laboratory room air (not clean-room air). Ensure that the instrument is on and there is air flow into the particle detector at the correct rate. The particle detector should count a high concentration of particles. The particle detector may even saturate while sampling room air. Place a high-efficiency particulate air (HEPA) filter on the inlet and make sure that the particle detector signal drops to a negligible level compared to the concentration to be measured.

8.2.3 Overall DMAS zero test with inlet filter

Reconnect the particle detector to the rest of the DMAS, apply clean air (through a HEPA filter with at least 99,99 % efficiency) to the DMAS inlet and run a particle number size distribution measurement. There should be no (or at most only a few counts in discontinuous, randomly distributed bins) particles across the whole particle number size distribution. If the particle detector detects particles, there are leaks in the DMAS, either in the components or in the interconnecting tubes.

8.2.4 Overall DMAS zero test with DEMC voltage set to 0 V

Make sure the aerosol inlet tube to the DEMC is open to normal room air (not clean-room air). Set up the appropriate sheath flow and sample aerosol flow rates within the DEMC and to the particle detector. Set the voltage applied to the DEMC to 0 V. The particle detector should count no (or at most only a few) particles in 1 min. If the particle detector detects particles:

a) the sheath/sample aerosol flow ratio could be too low and particles are diffusing into the monodisperse outlet of the DEMC. This can be corrected by decreasing the aerosol flow rate or increasing the sheath flow rate.

b) the flow rates within the DEMC are too high and turbulent conditions exist. If this is the case, reduce the flow rates to return to laminar flow.

8.3 Flow rate tests

The flow meters indicating the volumetric flow rates of sheath flow, excess flow, sample aerosol flow and mobility selected aerosol flow shall be tested. Regular calibration of these flow meters shall be made against a flow meter that is traceable to internationally accepted standards.

Volumetric flow rates govern the DEMC transfer function. If mass flow meters are used to measure or control flow rate, transformation from mass flow rate to volumetric flow rate is necessary.

The procedure described in 8.6.5.5 b) is to monitor correct sheath flow, see Wiedensohler et al. (2018) [75].

NOTE When the excess air is circulated and used as the sheath air, one can assume that the sample aerosol flow and the mobility selected aerosol flow are equivalent if the air leakage in the circulation circuit is verified to be negligible. In such cases, the flow meters need only be calibrated for the sheath air, the sample and the mobility selected aerosol flows.

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8.4 Voltage calibration

The voltage applied to the DEMC shall be calibrated against a voltmeter that is traceable to internationally accepted standards.

8.5 Charge conditioner test

Aging of ion sources (e.g. radioactive materials) in the charge conditioner may change the charge distribution for particles. If the tests for the entire DMAS (see 8.6, 8.7 and 8.8) fail, the charge conditioner can be one of the reasons.

Testing of the charge conditioners themselves should be done using particle number size distributions and number concentrations similar to those to be measured with the DMAS in which the charge conditioner is applied. Such tests require extensive laboratory equipment like sophisticated test aerosol generators and tandem DEMCs and test protocols that depend on the type of the charge conditioner. These tests are not subject of this document.

Charge conditioner integrity should be checked regularly at least by visual inspection of the device and, if applicable, by tests described in the device's user manual.

8.6 Calibration for size measurement

8.6.1 General

This subclause comprises two procedures for the size calibration of the DMAS. The first procedure describes size calibration for the standard operating mode, i.e. the so-called dynamic scanning mode. The second procedure is on calibration in the static step mode. Particle size standards described in 8.6.3 are used in both procedures.

8.6.2 Purpose of calibration

The tests and calibrations described in 8.2 to 8.5 are necessary to check accuracy and integrity of individual components of the DMAS. However, they are not necessarily sufficient for verification of the accuracy of sizing by a DMAS as an entire system. Therefore, a dynamic particle size calibration procedure for the standard DMAS sizing method is described in 8.6.4 and shall be carried out to test for accuracy and to calculate the dynamic sizing error. It includes the data inversion and correction algorithms given by the manufacturer. Therefore, it is relatively easy to perform and is suitable as a test method for typical users.

A size calibration is also feasible when the DMAS is statically set at fixed voltage(s), respectively fixed particle size(s). This is e.g. required in ISO 27891 for the particle number concentration calibration of CPCs. Here, the static sizing error of the DMAS has a considerable influence on the uncertainty. The static size calibration procedure is described in 8.6.5.

8.6.3 Particle size standards

Only particle size certified reference materials with reputable certificates should be used. A reputable certificate shall mean either one that has been produced by a laboratory accredited to ISO 17034 or an equivalent standard. The standard particles should be monodisperse and should have a certified diameter, d_c, with relative standard uncertainty, $u_{r,cert}$, equal to or less than 5 %.

DMAS calibration with standard monodisperse particles of a certified size requires due attention with respect to

— the method of dispersing these particles in air,

— the concentration of the particle dispersion in the liquid that has to be dispersed, which shall be sufficiently low to substantially avoid aerosol particles other than singlet particles,

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