



**International
Standard**

ISO 19996

**Charge conditioning of
aerosol particles for particle
characterization and the generation
of calibration and test aerosols**

*Conditionnement de la charge (électrique) des particules
d'aérosols pour la caractérisation de particules et la génération
d'aérosols pour calibration et essais*

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Contents

Page

Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols and abbreviated terms	2
5 General principle	2
5.1 General	2
5.2 Ionization sources	3
5.2.1 General	3
5.2.2 Sources with radioisotopes	3
5.2.3 Soft X-ray sources	5
5.2.4 Corona discharge	6
5.3 Charge conditioning	7
5.3.1 General	7
5.3.2 Bipolar charge conditioners	7
5.3.3 Unipolar charge conditioners	8
5.4 The charge distribution function	9
5.4.1 General	9
5.4.2 Charge distribution function for radioactive bipolar charge conditioners	9
5.4.3 Charge distribution functions for other bipolar and unipolar charge conditioners	9
6 Factors influencing the resulting charge distribution	10
6.1 General	10
6.2 Aerosol particle characteristics influencing the charge distribution	10
6.2.1 Particle size and surface area	10
6.2.2 Particle number and surface area size distribution and concentration	12
6.2.3 Particle pre-charge	12
6.3 Aerosol carrier gas characteristics influencing the charge distribution	13
6.3.1 Carrier gas composition	13
6.3.2 Carrier gas pressure and temperature	13
6.3.3 Carrier gas humidity	13
6.4 Charge conditioner operating parameters influencing the charge distribution	13
6.4.1 Aerosol flow rate	13
6.4.2 Ion production rate	14
6.5 Others	14
6.5.1 Surplus ions downstream of device	14
6.5.2 Particle losses to the chamber wall	14
6.5.3 Aerosol dilution in the charge conditioner	15
6.5.4 Generation of artefact particles	15
7 Operational parameters for device specification	15
8 Test procedures for determining the suitability of charge conditioners	15
8.1 Guidance to test procedures in the annexes	15
8.2 Charge conditioner performance verification	16
8.3 Particle losses in a charge conditioner	16
8.4 Particle generation rate	16
8.5 Charge distribution of bipolar charge conditioners	16
9 Cleaning and maintenance including safety issues	17
Annex A (informative) Implementation of bipolar steady-state charge conditioning	18
Annex B (informative) Performance test procedures for charge conditioners	24
Annex C (informative) Electrostatic precipitator to provide uncharged aerosol particles	37

Annex D (informative) **Concentration series test for charge conditioners** **39**

Annex E (informative) **Example set of tests for bipolar charge conditioners**..... **45**

Annex F (informative) **Test method for bipolar charge conditioners with ambient aerosols** **53**

Bibliography..... **55**

Foreword

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This document was prepared by Technical Committee ISO/TC 24, *Particle characterization including sieving*, Subcommittee SC 4, *Particle characterization*.

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

Charge conditioning of aerosol particles is the crucial process of establishing a known, size-dependent charge distribution on aerosol particles. Different designs for charge conditioners exist. In charge conditioners, aerosol particles are exposed to a cloud of ions of either both positive and negative polarities (bipolar charge conditioners) or a single polarity (unipolar charge conditioners).

The transport of the ions to the aerosol particles can either be driven by Brownian motion of the ions (diffusion charging) or by an electrical field (field charging). Since field charging is strongly biased by a particle's electrical properties (namely the relative permittivity), diffusion charging is generally used to condition aerosol particles:

- for particle size distribution measurement with the differential mobility analysing system (DMAS);
- for particle size classification with the differential electrical mobility classifier (DEMC).

Several parameters determine whether or not charge conditioning achieves its goal of either generating a mathematically describable bipolar steady-state charge distribution or a quantifiable unipolar mean charge. Examples for such parameters are the ion concentration, the particle concentration, the residence time of the particles in the ion cloud, the ion mass distribution or the ion mobility distribution. However, there is no standard methodology to specify the performance of charge conditioners.

The electrical mobility of aerosol particles is a physical particle property which is widely used for particle characterization (e.g. size distribution measurement with DMAS) and for particle classification (e.g. by DEMC). For a given particle size, the particles' electrical mobility is proportional to the net number of elementary charges on the particle. Therefore, the knowledge of particle charge distribution is an essential requirement for particle size distribution measurements with the DMAS and for particle size classification with the DEMC.

The purpose of this document is to provide a methodology to specify the performance of charge conditioners and for adequate quality control when charge conditioners are used in particle size and number concentration measurement or in particle size classification.

Other typical uses of charge conditioners which are not covered in this document are:

- conditioning of test aerosols for filter testing where particle charge has an influence on the test results;
- particle charge reduction during the droplet evaporation in an electrospray aerosol generator, where the very high unipolar charge of the sprayed solution or dispersion droplets can lead to the unwanted disintegration of the droplets due to exceeding the Rayleigh limit during droplet evaporation;^{[34]-[36]}
- diffusion chargers (DC) in particle number devices (PND) that are typically used as robust, compact systems to measure particle number concentration in the exhaust emission of passenger cars, light and heavy duty cars under real driving emissions (RDE) as well as under periodical technical inspections (PTI) in Europe. The charging process in such a device is provided by a diffusion charger, which is charging the aerosol in a positive unipolar diffusion state. Typically, a thin wire is used as a high voltage electrode to generate positive ions. The ions are injected through a grounded grid into buffer volume where they are mixed with the particles. Afterwards, the charged aerosols will be counted in a two stage procedure by an pulsed precipitator and in an Faraday cup aerosol electrometer (FCAE);^[37,38]
- large-scale ionizers combined with electrostatic precipitators (ESP) for cleaning flue gases of waste incinerators or power plants fired with solid fuels. In the ESP, a corona discharge generates ions which charge the flue gas particles (usually fly ash) by diffusion and field charging (depending on the particle size). Subsequently, the particles are deflected by electrophoresis in the ESP's electrostatic field and deposited on grounded collection electrodes. Industrial ESP are usually several tens of meters high and consist of a multi-stage configuration to optimize the overall collection and gas cleaning efficiency.

Charge conditioning of aerosol particles for particle characterization and the generation of calibration and test aerosols

1 Scope

This document specifies requirements and provides guidance for the use of charge conditioners for aerosol particles, especially for particle characterization and for the generation of calibration and test aerosols.

This document provides a methodology to specify the performance of charge conditioners and for adequate quality control, with respect to their application in:

- particle size and concentration measurement with differential mobility analysing systems (DMAS);
- particle size classification with differential electrical mobility classifiers (DEMC).

For these applications, this document covers particle charge conditioning for particle sizes ranging from approximately 1 nm to 1 μm and for particle number concentrations at the inlet of the charge conditioner up to approximately 10^7 cm^{-3} .

This document does not address specific charge conditioner designs or other applications besides those specified in Clause 1.

Radiation safety for charge conditioners with radioactive sources or x-ray tubes is not covered by this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 15900, *Determination of particle size distribution — Differential electrical mobility analysis for aerosol particles*

ISO 27891, *Aerosol particle number concentration — Calibration of condensation particle counters*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15900, ISO 27891 and the following apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1 charging probability

$f_p(d)$

ratio of the number concentration of particles exiting a charge conditioner with p charges to that of particles exiting the charge conditioner at all charge states, at particle size d

Note 1 to entry: p charges are 0, ± 1 , ± 2 , etc.

Note 2 to entry: The charging probability with respect to the number concentration entering (instead of exiting) the charge conditioner is called "extrinsic charging probability".

3.2 charge distribution function

either mathematical or empirical, or both, description of a conditioned distribution of particle size dependent *charging probability* (3.1)

3.3 electrostatic precipitator ESP

device for removing charged particles from an airflow by electrophoresis to generate an uncharged aerosol

Note 1 to entry: More information on ESPs is given in [Annex C](#).

3.4 ion mobility distribution

number density distribution with respect to the electrical mobility of the ionic molecular clusters that are responsible for the charging of aerosol particles in a charge conditioner

4 Symbols and abbreviated terms

For the purpose of this document, the following symbols and abbreviated terms apply.

CPC	condensation particle counter	
DEMC	differential electrical mobility classifier	
DMAS	differential mobility analysing system	
ESP	electrostatic precipitator	
d	particle diameter	m
$f_p(d)$	charging probability	dimensionless
N	number concentration of aerosol particles	m ⁻³
N_i	number concentration of ions	m ⁻³
p	number of net elementary charges on a particle	dimensionless
t	residence time of an ion in charge conditioner	s

5 General principle

5.1 General

The function of the charge conditioner in this document is to establish a known size-dependent, steady-state charge distribution on the sampled aerosol prior to the size classification process in electrical mobility classifiers like the DEMC. The charge distribution on the particles can either be bipolar or unipolar.

All charge conditioners can be regarded as ionization sources because they generate ions of either one polarity or both polarities in the carrier gas. These ions interact with the particles to generate a charge distribution. The characteristics of ionization sources frequently used for charge conditioning are outlined in 5.2.

Since charge conditioners are used to achieve steady state charge distribution in the aerosol sample flow, the charge conditioner shall, by design or by measurement, perform correctly and not produce artefact particles.

In its simplest form, a charge conditioner, such as that used in a DMAS, consists of an aerosol inlet, aerosol outlet, ionizing source, charging zone and enclosure.

5.2 Ionization sources

5.2.1 General

There are three common types of ionization sources for charge conditioning.

- Radioisotopes.
- Soft X-rays.
- Corona-discharges.

Other, less common ionization sources are included in [Table 1](#).

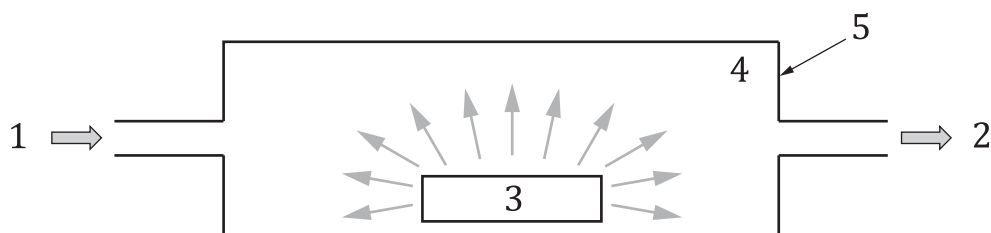
5.2.2 Sources with radioisotopes

5.2.2.1 General

Radioisotope charge conditioners generally contain a sealed radioactive source. This device acts as a bipolar diffusion charge conditioner. It produces both negative and positive ions in the carrier gas. The radiation generates, so called, primary ions like N_2^+ and O_2^+ and free electrons in the carrier gas. These ions are short-lived. Some of them attach themselves to neutral molecules, which then coagulate into relatively stable ion clusters. Diffusion (Brownian movement) leads to collisions between these ions and the aerosol particles and thus to charge transfer to the particles.

Either alpha or beta radiation can be applied for air ionization. Alpha radiation with its very high linear energy transfer is able to produce high ion concentrations in a small charging volume. This is an advantage over beta radiation, where the charging volume must be bigger. As a result, the particle residence time in a radioactive charge conditioner with beta radiation is typically longer, which is a disadvantage with respect to diffusion losses. On the other hand, alpha radiation sources can easily be shielded, e.g. by a very thin layer of dust. Surface contamination can reduce the resulting ion concentration in charge conditioners with alpha sources.

[Figure 1](#) shows a schematic example of the design of a radioisotope charge conditioner.

**Key**

- | | | | |
|---|---------------------|---|---------------|
| 1 | aerosol inlet | 4 | charging zone |
| 2 | aerosol outlet | 5 | enclosure |
| 3 | radioisotope source | | |

Figure 1 — Schematic example of a radioisotope charge conditioner

The most commonly used radioactive isotopes are:

- Krypton 85 (^{85}Kr).
- Americium 241 (^{241}Am).
- Polonium 210 (^{210}Po).
- Nickel 63 (^{63}Ni).

Their properties are explained in 5.2.2.2 to 5.2.2.5.

NOTE Sealed radioactive sources are classified based on ISO 2919, [71] which provides tests and a classification system, e.g. for ranges of temperature, pressure, puncture, impact and vibration.

5.2.2.2 Krypton 85 (^{85}Kr)

^{85}Kr is a beta emitter (with 0,43 % gamma radiation probability of 514 keV) with a half-life of 10,78 years. The maximum beta energy is 687 keV. Krypton is a noble gas, substantially reducing the health risk in case of leakage or damage to the source. In nearly all sources, the ^{85}Kr gas is contained in a small-diameter, sealed, stainless steel tube. This tube is contained inside a larger-diameter stainless steel or aluminium housing. Aerosol passes axially through the housing that contains the ^{85}Kr tube. Part of the beta radiation is absorbed in the steel or aluminium that makes up the tube and the housing, thus producing Bremsstrahlung that also contributes to ion production. It is recommended to use lead shielding if possible.

5.2.2.3 Americium 241 (^{241}Am)

^{241}Am is an alpha emitter (with negligible additional beta and gamma radiation) with a half-life of 433 years. Sealed sources of this metal are available as strips covered with a very thin gold, palladium, or gold and palladium alloy film. The alpha energy is 5,5 MeV.

5.2.2.4 Polonium 210 (^{210}Po)

^{210}Po is an alpha emitter with a half-life of 138 days. Due to their short half-life, ^{210}Po sources should be replaced annually or more often. The metalloid ^{210}Po is available in the form of gold-coated, typically embedded in a protective housing. Its alpha energy is in the range between 4 MeV and 5,3 MeV.

5.2.2.5 Nickel 63 (^{63}Ni)

^{63}Ni is a beta emitter (100 %) with a half-life of 100,1 years. Its beta energy is 67 keV; the decay product is stable ^{63}Cu . ^{63}Ni foils are also used, as ionisation source in GC-MS for example. Unsealed as well as sealed (inactive Ni overplating) foils, with up to 100 MBq, are commercially available.

NOTE 100 MBq is the free limit in the EU.

5.2.2.6 Licensing and precautions for radioisotope sources

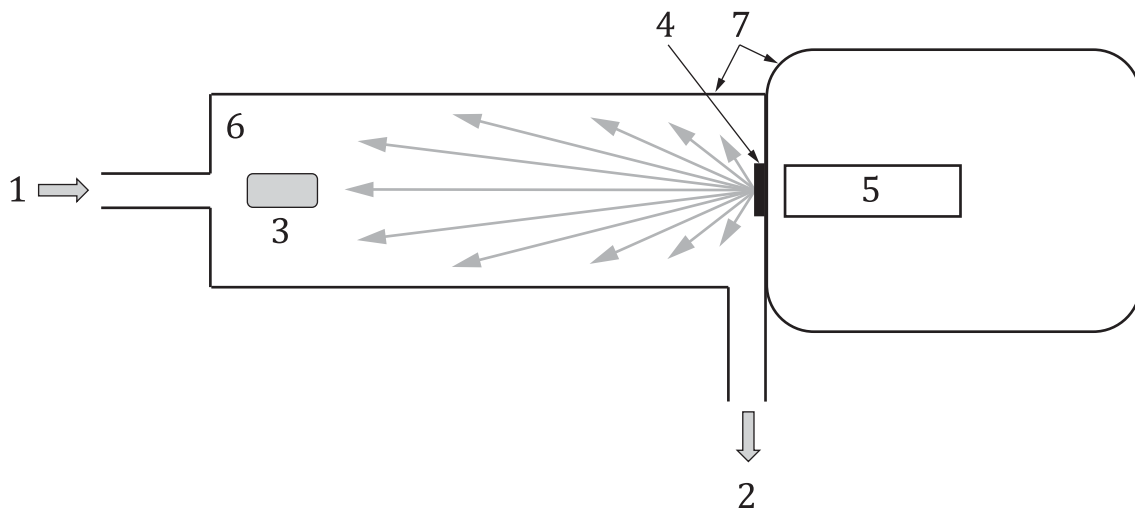
The use, transportation and disposal of radioisotopes is regulated by government authorities. Basic international standards and guidelines are, for example, set by commissions of the United Nations, such as IAEA, ICRP, ADR, etc. The licensing, shipping and disposal regulations that govern radioactive sources vary from nation to nation.

5.2.3 Soft X-ray sources

5.2.3.1 General

Soft X-ray sources emit X-rays in the energy range below 10 keV. Soft X-rays are a very efficient source for charge conditioning because they have energies that are much higher than the ionization threshold of all molecules, thus creating an abundance of active ions. This device acts as a bipolar diffusion charge conditioner, comparable to sources with radioisotopes. A stainless steel or aluminium housing is irradiated with X-rays from a source. The aerosol flows through the housing from an inlet to an exit port. A radiation window (e.g. beryllium) protects the X-ray source from particle impact and also attenuates the radiant flux and radiation energy to adjust the ion concentration. X-ray blockers can prevent X-rays from exiting through the aerosol ports. While radioisotope sources emit radiation continuously, X-ray sources can be turned on and off.

[Figure 2](#) shows a schematic example of the design of a soft X-ray charge conditioner. While in this example, the aerosol flow is directed towards the attenuation window, other designs exist where the flow is reversed.



Key

- | | | | |
|---|--------------------------|---|---------------|
| 1 | aerosol inlet | 5 | x-ray source |
| 2 | aerosol outlet | 6 | charging zone |
| 3 | x-ray blocker (optional) | 7 | enclosure |
| 4 | attenuation window | | |

Figure 2 — Schematic example for a soft X-ray charge conditioner

5.2.3.2 Licensing and precautions for soft X-ray sources

The use of soft X-ray sources can be regulated by international, national or local government authorities, or all. Regulations can vary from nation to nation.

Users shall conform to manufacturers' instructions.

5.2.4 Corona discharge

Corona discharge can function as a source for both negative and positive ions in the carrier gas. Either a single corona electrode operated with DC-high voltage (for ions of one polarity) or with AC-high voltage (for two ion polarities), or two separate corona electrodes (one for each ion polarity) can be used.

NOTE If an aerosol electrometer is used as a particle detector immediately downstream of the charge conditioner (without the DEMC), an ion trap is possibly necessary as an additional element to eliminate any remaining free ions from the charge-conditioned aerosol. Otherwise an aerosol electrometer will measure these free ions as an additional current.

Figures 3 and 4 show schematic examples of the design of corona discharge charge conditioners.

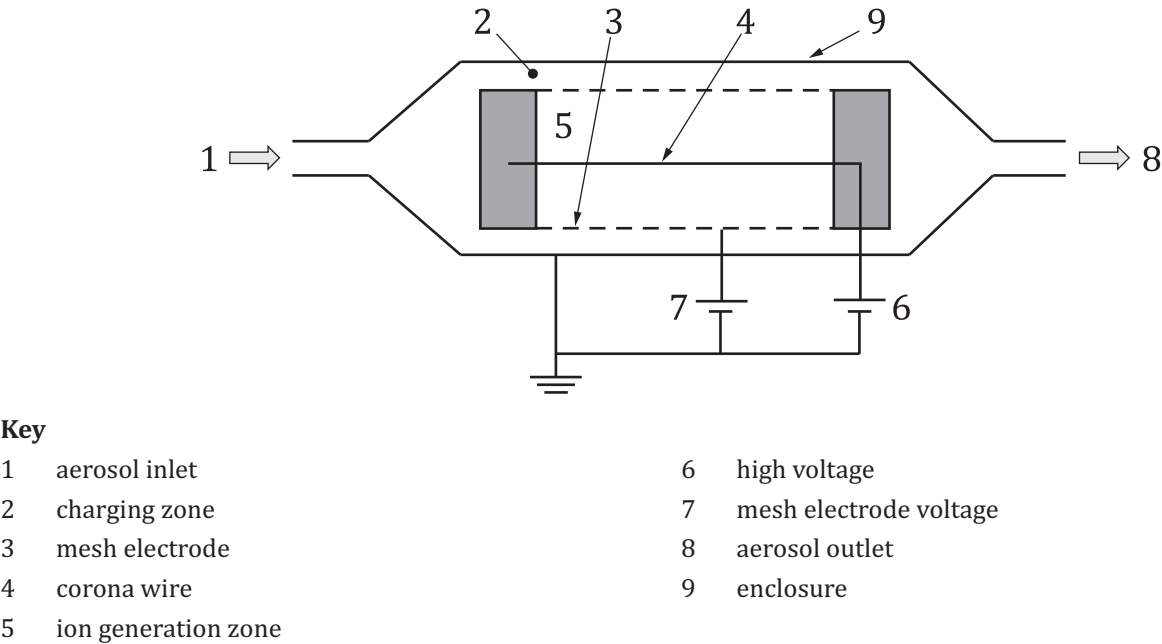


Figure 3 — Schematic example for a mesh corona discharge charge conditioner

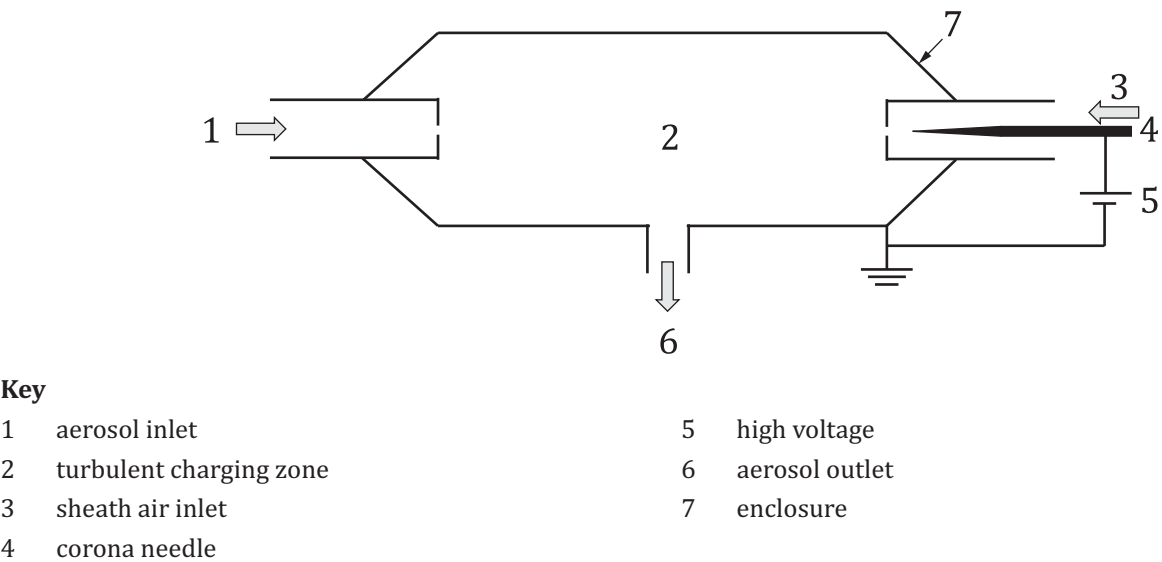


Figure 4 — Schematic example for a counter-flow corona discharge charge conditioner

5.3 Charge conditioning

5.3.1 General

In order to calculate the particle size distribution from the measured electrical mobility distribution, a known particle size-dependent distribution of electrical charges shall be generated on the aerosol particles, described by the charge distribution function, $f_p(d)$. Charge conditioners upstream of a DEMC are used for this purpose.

In a gaseous medium containing aerosol particles and a sufficient concentration of unipolar ions or ions of both polarities, a charge distribution will develop on the particles. As the dominant driving forces are the random thermal diffusion of the ions and the collision between ions and aerosol particles, the terms bipolar or unipolar diffusion charging are frequently used for these types of charge conditioning. The main advantage of diffusion charging over other methods is that it depends only weakly upon aerosol particle material.^[16] Subclauses 5.3.2 and 5.3.3 describe the characteristics of bipolar and unipolar diffusion charging.

In some charge conditioner designs, the ion transport is deliberately influenced by AC- or DC-electric fields and sheath air flows.

The particle charging efficiency 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 their residence time, t , which is the interaction time of aerosol particles with the ions.

The $N_I \cdot t$ product reached in a radioactive charge conditioner depends on the type and energy of the radiation of the isotope, on the activity and geometry of the sealed source, on the geometry of the housing, on the flow rate and concentration of the aerosol through the housing and also on the composition of the carrier gas. Similarly, the $N_I \cdot t$ product reached in a soft X-ray charge conditioner depends on the X-ray energy and the radiant flux, the radiation field geometry, the flow rate and concentration of the aerosol flow through the housing and on the composition of the carrier gas (see [Clause 6](#)).

[Table 1](#) gives an overview on charge conditioners. There is a list of literature provided at the end of the document.

Table 1 — Overview on charge conditioners and selected references

Category	Type	Reference
Bipolar charge conditioners	Radioactive charge conditioner (RC) ^a	[1], [7], [49], [50]
	Soft-X-ray charge conditioner (SXRC)	[1], [31], [32], [49] – [53]
	Bipolar corona ionizer (BCI)	[54] – [59]
	Surface-discharge microplasma aerosol charger (SMAC) ^a	[3], [60] – [64]
Unipolar charge conditioners	Positive unipolar corona discharge (PCD) charge conditioner	[5], [12], [49], [50], [65]
	Negative unipolar corona discharge (NCD) charge conditioner	– [67]
^a Can also be applied for unipolar charge conditioning.		

5.3.2 Bipolar charge conditioners

Bipolar charge conditioners (also traditionally called aerosol neutralizers) produce ions of both polarities (i.e. positive and negative ions). Neutral particles can acquire charge while highly charged particles can discharge themselves by capturing ions of the opposite polarity. Bipolar charge conditioners differ by the way the ions are generated.

- Radioactive bipolar diffusion charge conditioners generate ions in the carrier gas by α - or β -radiation from a radioactive isotope.
- X-ray bipolar diffusion charge conditioners use soft-X-rays (< 10 keV) for ion generation in the carrier gas.

In these two charge conditioner types, the ions are produced directly in the carrier gas and diffuse to the aerosol particles by Brownian motion.

- Bipolar corona ionizers (BCI) use an arrangement of two DC-corona ionizer stages (one for each polarity). Ions of opposite charge are produced in separate sections and are subsequently mixed with the aerosol. In another variant, bipolar ions are produced by AC-corona discharging.

5.3.3 Unipolar charge conditioners

Besides the widely used bipolar steady-state charge distribution, unipolar charge conditioning can also be used to achieve a defined charge distribution. In a unipolar charge conditioner, ions of either positive or negative polarity are produced (e.g., by a corona discharge process or separation of one ion polarity in an electric field). Like in bipolar charging, diffusion charging is advantageous because variations caused by the composition of the particles can be neglected for diffusion charging.

Unipolar charging can achieve higher charging probabilities than bipolar charging. This is an advantage if small particles ($d < 20$ nm) are to be measured. Due to the higher charging probability, more particles are classified by the DEMC. This leads to better counting statistics in a DMAS. On the other hand, larger particles ($d > 100$ nm) carry significantly more multiple charges compared to bipolar charge conditioning. This makes the data inversion more complex and reduces the size resolution of large particles. A variety of unipolar charge conditioners for aerosol particles have been described and built; see, for example, References [44], [45], [46], [47] and [48].

Corona discharge is produced by a strong nonuniform electrostatic field, such as that between a needle and plate or a concentric thin wire and a tube. The electric field and space charge effects result in repulsion of ions of polarity opposite to that of the wire which can lead to positively or negatively charged particles. There are two designs for corona discharge charge conditioners:

- Negative corona discharge charge conditioner.

The discharge electrode is held at high negative potential. The free electrons are repelled from the electrode and can attach to air molecules to form negative ions. Ozone is generated as a by-product which makes this design not favourable for aerosol charging.

- Positive corona discharge charge conditioner.

In positive corona discharge charge conditioners, the discharge electrode (wire or tip) is held at high positive potential. In this case the free electrons from the corona discharge are attracted to the electrode and do not need to be absorbed. Most commercially available charge conditioners use positive ions due to the fact that the process is stable by controlling the corona current and the emission of ozone can be avoided.

Among the group of positive corona charge conditioners are indirect corona charge conditioners and turbulent jet charge conditioners. Indirect corona charge conditioners shield the particle charging zone from the corona discharging zone in order to reduce particle losses. A grounded electrode in the aerosol flow can be applied as a trap for excess ions. Turbulent jet charge conditioners completely separate the ion generation from the particle charging zone. This leaves the charging zone free of electrical fields and reduces particle losses to a minimum. Ions are transported into the particle charging zone by an additional flow, which dilutes the aerosol flow at the exit.

NOTE Corona charge conditioners that apply field charging, in contrast to diffusion charging, are not considered for measurement purposes here because of their increased particle material dependence.

Other charge conditioning processes such as static electrification, photoionization, thermionic emission, self-charging of radioactive particles and agglomeration are not considered because of their very restricted controllability and usability to charge conditioning in measuring devices. However, some of these processes should be taken into account as disturbances.

5.4 The charge distribution function

5.4.1 General

The particle size-dependent charge distribution function, $f_p(d)$, shall be known in order 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. The conditioned charge distribution 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 equations or tabulated data, approximating the size-dependent charge distribution by either theoretical models or empirical data, or both.

5.4.2 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 [Formulae \(A.10\)](#) and [\(A.11\)](#) which are derived from an approximation to the theoretical models (see Reference [17] in combination with the result from Reference [18]). [Table 2](#) shows some numerical results. Unless explicitly specified differently in the measurement report, [Formulae \(A.10\)](#) and [\(A.11\)](#) or values in [Table 2](#) shall be used for the determination of $f_p(d)$ for radioactive bipolar charge conditioners.

Table 2 shows the bipolar charge distribution $f_p(d)$ for spherical particles in air (293,15 K, 101,3 kPa), produced by radioactive charge conditioners (see [Formulae \(A.10\)](#) and [\(A.11\)](#)).

Table 2 — Bipolar charge distribution $f_p(d)$ produced by radioactive charge conditioners

d (nm)	Charge distribution												
	-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

5.4.3 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](#) can be helpful for the experienced user to calculate a charge distribution function for a given bipolar charge conditioner. [Annex A](#) also shows an example of the charge distribution function for a charge conditioner based on an X-ray ionization source.

The charging of particles in unipolar charge conditioners depends on individual designs and operating parameters. Therefore, no general approximation for the charge distribution function can be given for the variety of unipolar charge conditioners.

6 Factors influencing the resulting charge distribution

6.1 General

The purpose of operating a charge conditioner, as described in this document, is to achieve either:

- a steady state;
- equilibrium charge distribution (bipolar charge conditioners);
- a well characterized and repeatable charge distribution (unipolar charge conditioners).

If charge conditioning is done for particle measurement purposes (e.g. for measurements with the DMAS), any changes in the aerosol properties during the charging process must be negligible with respect to the result of the measurement.

All charge conditioners described have individual permissible upper particle concentration limits and particle size dependent charging efficiencies. Their respective charge distribution functions, $f_p(d)$, depend on ion concentrations, ion mass and ion mobility, as well as on residence time and concentration of particles. Situational factors such as carrier gas composition, purity, humidity and temperature can also influence the performance. Charge conditioner manufacturers should provide the respective charge distribution function and describe the conditions under which the device performs in a predictable way and does not produce artefacts.

Considering the influence of operating conditions, there is a major difference between bipolar and unipolar charge conditioners.

- In bipolar charge conditioners, the resulting charge distribution depends on the ion mass distribution and the ion mobility distribution. Since the necessary time to reach steady state conditions is very small compared to the residence time of the particles in the charging zone, the steady state charge distribution will be reached and remain unchanged as long as the particle concentration, in combination with the particle size distribution, does not exceed the design-based ($N_1 \cdot t$ -product based) limit of the charge conditioner.
- In unipolar charge conditioners, the achieved mean charge per particle and the charge distribution depend on the $N_1 \cdot t$ product. Therefore, besides the ion properties (mass and mobility), the ion concentration profile within the charging region as well as the aerosol flow rate through the charge conditioner must be maintained within narrow tolerances to guarantee reproducible operation achieving the expected charge distribution.

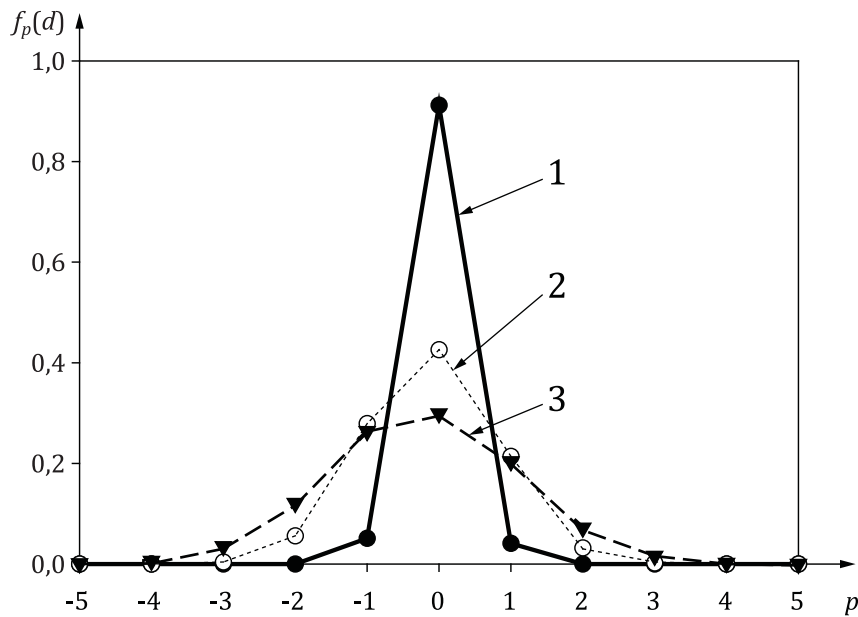
[Clause 6](#) covers the influence of aerosol particle and carrier gas characteristics as well as the influence of charge conditioner operating parameters (and others) on the resulting charge distribution and eventual changes in aerosol properties. Sub-clauses [6.2](#) to [6.5](#) cover topics under the assumption that all other conditions do not change.

6.2 Aerosol particle characteristics influencing the charge distribution

6.2.1 Particle size and surface area

The mean number of elementary charges per particle increases and the charge distribution widens with increasing particle size.

[Figure 5](#) shows a comparison of the steady state, equilibrium charge distribution for spherical particles with a diameter of 10 nm, 100 nm and 200 nm, calculated with the approximation for radioactive ionization sources in a bipolar diffusion charge conditioner as described in Reference [\[17\]](#), see [A.4](#).



Key

p	number of net elementary charges on a particle	1	$d = 10 \text{ nm}$
$f_p(d)$	charging probability	2	$d = 100 \text{ nm}$
		3	$d = 200 \text{ nm}$

Figure 5 — Bipolar charge distribution for spherical particles with a diameter of 10 nm, 100 nm and 200 nm

Similar behaviour is found for unipolar diffusion charge conditioners. [Figure 6](#) shows a comparison of the unipolar charge distribution for spherical particles with a diameter of 10 nm, 100 nm and 200 nm, in a mixing type charge conditioner, calculated with the approximation for a unipolar charge conditioner (that is, ion jet and turbulent mixing) described in Reference [\[12\]](#).

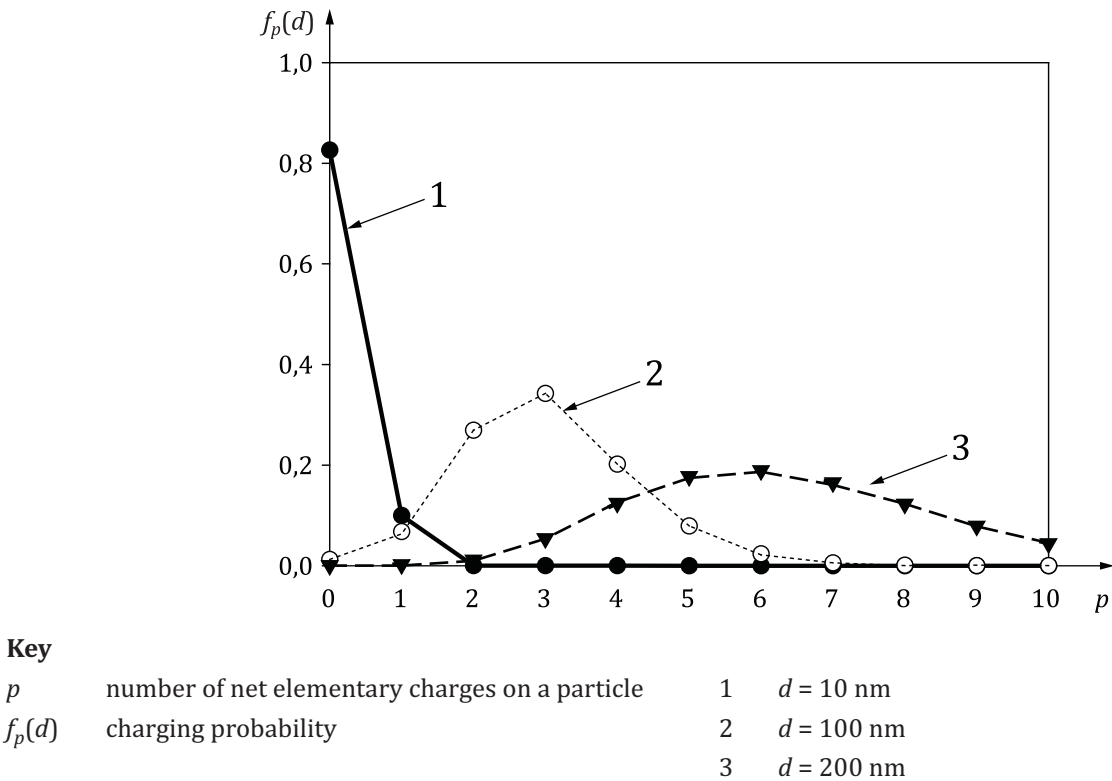


Figure 6 — Unipolar charge distribution for spherical particles with a diameter of 10 nm, 100 nm and 200 nm

Classical particle charging models as discussed in [Annex A](#) assume spherical particles and hence apply the sphere’s geometrical diameter and surface area to determine ion attachment. For irregularly shaped, non-spherical particles, the ion attachment equivalent surface area must be used to determine the ion attachment when calculating the average charge per particle and the charge distribution.^[39]

6.2.2 Particle number and surface area size distribution and concentration

The particle concentration to be charged shall be limited in such a way that the depletion of ions due to ion attachment to the particles does not lead to significantly reduced charges on the particles.

Whether or not the expected charge distribution is achieved in a charge conditioner due to ion depletion depends on the total ion attachment surface area concentration. While steady state conditions are reached (e.g. for a certain particle number concentration of monodisperse particles of a given size), it can eventually not be reached when a wide particle size distribution with the same number concentration is present. The presence of larger particles in the size distribution increases the ion depletion.

6.2.3 Particle pre-charge

In bipolar charge conditioners, the ion concentration can be insufficient to compensate high pre-charge while the same aerosol, if uncharged, reaches steady state conditions.

Unipolar charge conditioning is also affected by the pre-charge (also known as a primary charge) on the particles. Unipolar charge conditioning will fail if the particles entering the device already carry a charge level of the same polarity as the ions which is higher than the expected steady state charge level. Such higher pre-charge cannot be reduced by ions of the same polarity. Some unipolar charge conditioners minimize this effect by a two-stage design, where the first charge conditioner stage operates at the opposite polarity.

6.3 Aerosol carrier gas characteristics influencing the charge distribution

6.3.1 Carrier gas composition

In a different carrier gas than air (e.g. pure nitrogen or argon), the ratio of the electrical mobility of positive and negative ions will change. This will lead to a different steady state (equilibrium) charge distribution for bipolar charge conditioners (see Reference [9]).

Furthermore, particle formation from precursor gases (e.g. SO₂ or pinenes) can increase in the presence of the high ion concentration in the charge conditioner. Ozone produced by the corona plasma in unipolar chargers can also serve as a particle precursor. It should be checked prior to measurements, e.g. with a DMAS that particle generation in the charge conditioner is insignificant compared to the measured particle concentration. A system zero test (refer to ISO 15900:2020, 8.2.3) with the aerosol to be measured is helpful to uncover particle generation in the charge conditioner.

6.3.2 Carrier gas pressure and temperature

A change in either temperature or pressure, or both, changes the ion electrical mobility distribution but does not change the ratio of the electrical mobility of positive and negative ions, because electrical mobilities are directly proportional to temperature or inversely proportional to pressure. The steady state (equilibrium) charge distribution for bipolar charge conditioners, thus, will not change (see Reference [40]).

The charge distribution for unipolar conditioners, however, will change with carrier gas pressure and temperature since the ion mobility distribution is changed.

6.3.3 Carrier gas humidity

Depending on the relative humidity (RH) of the carrier gas, the ion mobility distribution will change. With increasing RH, the mobility of negative ions, especially, increases. The mobility of positive ions remains unchanged. See Reference [32] for further information. This changes the steady state (equilibrium) charge distribution for bipolar chargers as well as the charge distribution for negative unipolar chargers under otherwise unchanged conditions.

6.4 Charge conditioner operating parameters influencing the charge distribution

6.4.1 Aerosol flow rate

6.4.1.1 Particle residence time in the charging volume

The particle residence time in the charging volume of a charge conditioner depends on the aerosol flow rate through the charging volume.

For typical designs of bipolar charge conditioners, the residence time of the particles in the charging volume (seconds) is not a significant parameter since it is much longer than the time required to achieve the steady state charge distribution (milliseconds), see Reference [33].

For unipolar charge conditioners, the achieved charge distribution (for otherwise unchanged conditions) depends on the residence time in the charging volume. The mean charge per particle increases with increasing residence time.

The residence time cannot be assumed to be simply proportional to the flow rate, since the particle velocity field can change with changing flow rate; for example, stagnation zones can develop under certain flow conditions. Therefore, the geometric design of the charge conditioner has a strong influence on the residence time.

6.4.1.2 Particle concentration profile (mixing state) in the charging volume

The particle concentration profile and the mixing state of the aerosol in the charging volume can change depending on the following:

- aerosol flow rate;
- geometric design of the charge conditioner;
- spatial particle and ion concentration profiles.

Extreme cases are laminar particle stream lines directly from the inlet to the outlet of the charging chamber presenting a high particle concentration to the ion cloud versus a homogeneously mixed aerosol inside the whole chamber presenting a much lower concentration. Obviously, these two cases can lead to very different particle concentration to ion concentration ratios.

Poor mixing conditions in the charging chamber can significantly reduce the maximum allowed particle concentration to reach steady state conditions in a bipolar charge conditioner.

For unipolar charge conditioners, the average $N_1 \cdot t$ product will be very different for the extreme cases covered in [6.4.1.2](#), therefore the resulting particle charge will also be significantly different.

6.4.2 Ion production rate

The ion concentration in the charging volume (and therefore the charging capacity of a charge conditioner) is directly linked to its ion production rate.

In charge conditioners with radioactive sources, the ion production rate decreases over time due to the decay of the radionuclide. After one half-life of the used radionuclide, the activity (decays per second) and hence the ion production rate is reduced to 50 %. Depending on the radiation type and energy of the radiation emitted by the radioactive source, surface contamination can also influence the ion production rate. This reduction can become significant especially for alpha radiation, which is easily shielded by a thin layer of solid or liquid contamination.

The ion production rate from electrically controlled ion sources (e.g. corona discharge or x-ray tubes) can be user-controllable by design; it can also vary due to malfunction of the control circuit.

The performance of the corona needle or wire in a charge conditioner can degrade either due to erosion or due to the build-up of deposited materials. The latter was, for example, reported if the gas flow around the corona needle contains traces of out-gassings from silicone tubing.^[41] Because of performance degradation, the ion production rate at unchanged corona voltage is reduced.

In a bipolar charge conditioner, a decrease in ion production rate will result in a proportional decrease in allowed particle concentration at a given size distribution. In a unipolar charge conditioner, decreasing ion production rate will also change the charging efficiency and, therefore, the mean charge per particle and the charge distribution.

6.5 Others

6.5.1 Surplus ions downstream of device

Depending on the charge conditioner's design, ions can leave the charging chamber through its exit port. In instruments which detect the electrical charge of the particles (e.g. charger and electrometer combinations for total Fuchs surface area concentration or lung-deposited surface area concentration measurement), these ions can bias the measurement. An electrostatic ion trap (precipitator) is used in such cases to separate surplus ions from the aerosol.

6.5.2 Particle losses to the chamber wall

Particle losses to the walls of the charging chamber are mainly due to diffusion (Brownian and eventually turbulent). If charged particles pass through an electrical field in a corona charger, electrophoretic losses can also occur.

Internal losses are already included in the (measured) extrinsic charge distribution of a charge conditioner. However, charge distribution measurements are typically made at a nominal flow rate through the device.