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Standard

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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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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 concertation 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.

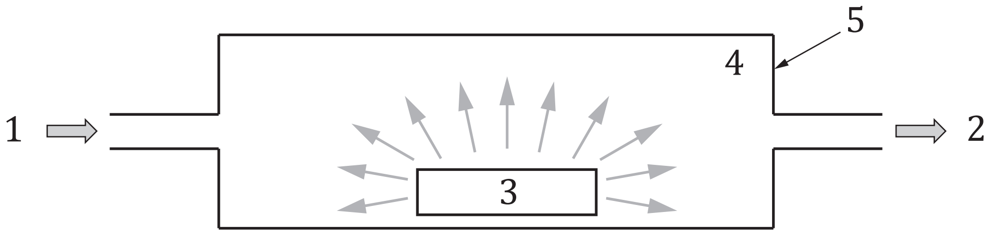
5.2.2 Sources with radioisotopes

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

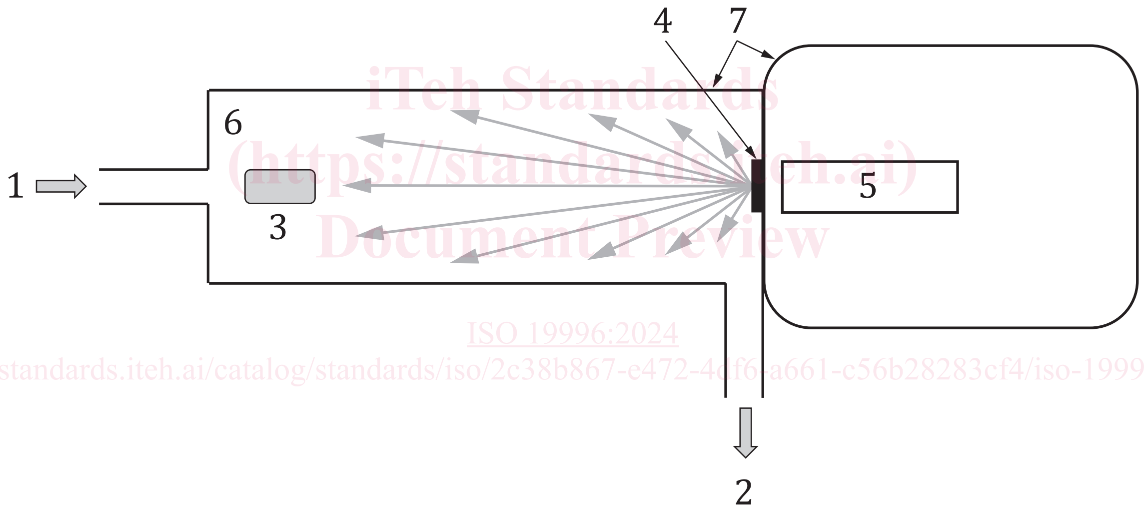
The use, transportation and disposal of radioisotopes is regulated by government authorities. Basic international standards and guidelines are, for example, set by commissions of the United Nations, such as IAEA, ICRP, ADR, etc. The licensing, shipping and disposal regulations that govern radioactive 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
2 aerosol outlet
3 x-ray blocker (optional)
4 attenuation window
5 x-ray source
6 charging zone
7 enclosure

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.

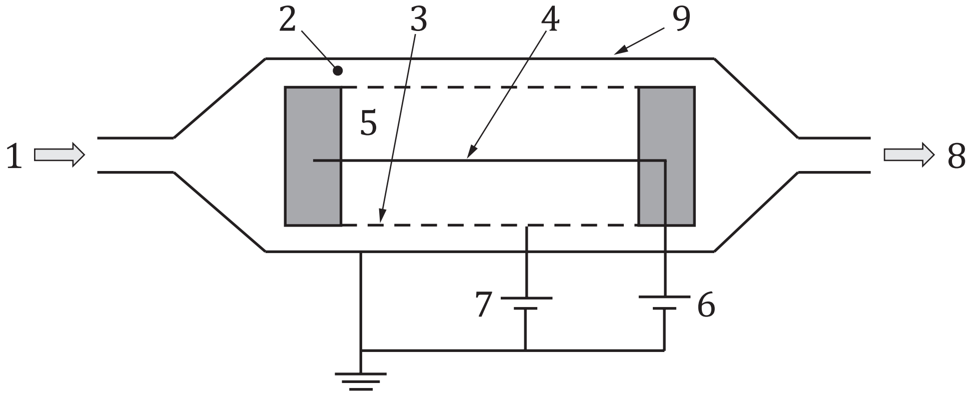
Users shall conform to manufacturers’ instructions.

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.

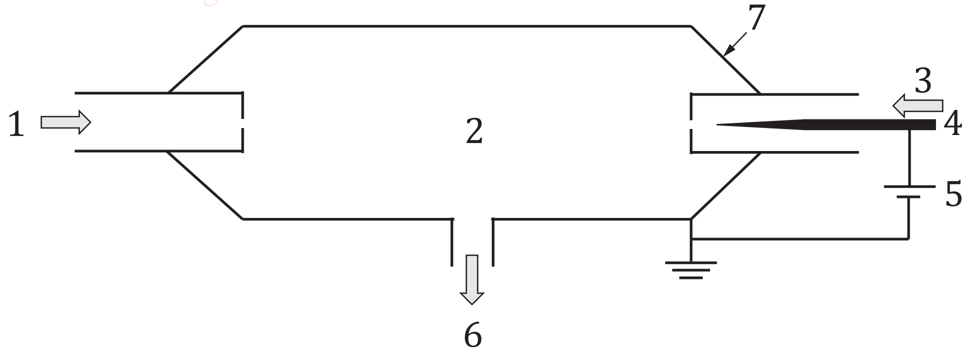
Figures 3 and 4 show schematic examples of the design of corona discharge charge conditioners.



Key

1 aerosol inlet
2 charging zone
3 mesh electrode
4 corona wire
5 ion generation zone
6 high voltage
7 mesh electrode voltage
8 aerosol outlet
9 enclosure

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



Key

1 aerosol inlet
2 turbulent charging zone
3 sheath air inlet
4 corona needle
5 high voltage
6 aerosol outlet
7 enclosure

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 $N_\mathrm{I}{\cdot}t$ 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 $N_\mathrm{I}{\cdot}t$ 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 $N_\mathrm{I}{\cdot}t$ 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] – [67]
	Negative unipolar corona discharge (NCD) charge conditioner	

[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.