Atmospheric Aerosol Physics, Physical Measurements, and Sampling

General Definitions & Particle Diameters

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Tropospheric Research

Background

Physical aerosol particle measurements

Physical properties of atmospheric aerosol particles are important to understand climate- and air-quality-related aerosol effects.

Important for atmospheric data are comparable and high quality measurements under standardized sampling conditions.

Physical and optical particle variables

Particle number concentration and size distribution

Particle light scattering and absorption coefficient

Equivalent Black Carbon (eBC)

Hygroscopicity: growth factor and mixing state

Volatility: size distribution and mixing state

Definitions

General Definitions

Definition of an aerosol

Solid and /or liquid particles suspended in a gas

Coarse Particles

Particles larger than 1 µm in diameter

Fine Particles

Particles smaller than 1 µm in diameter

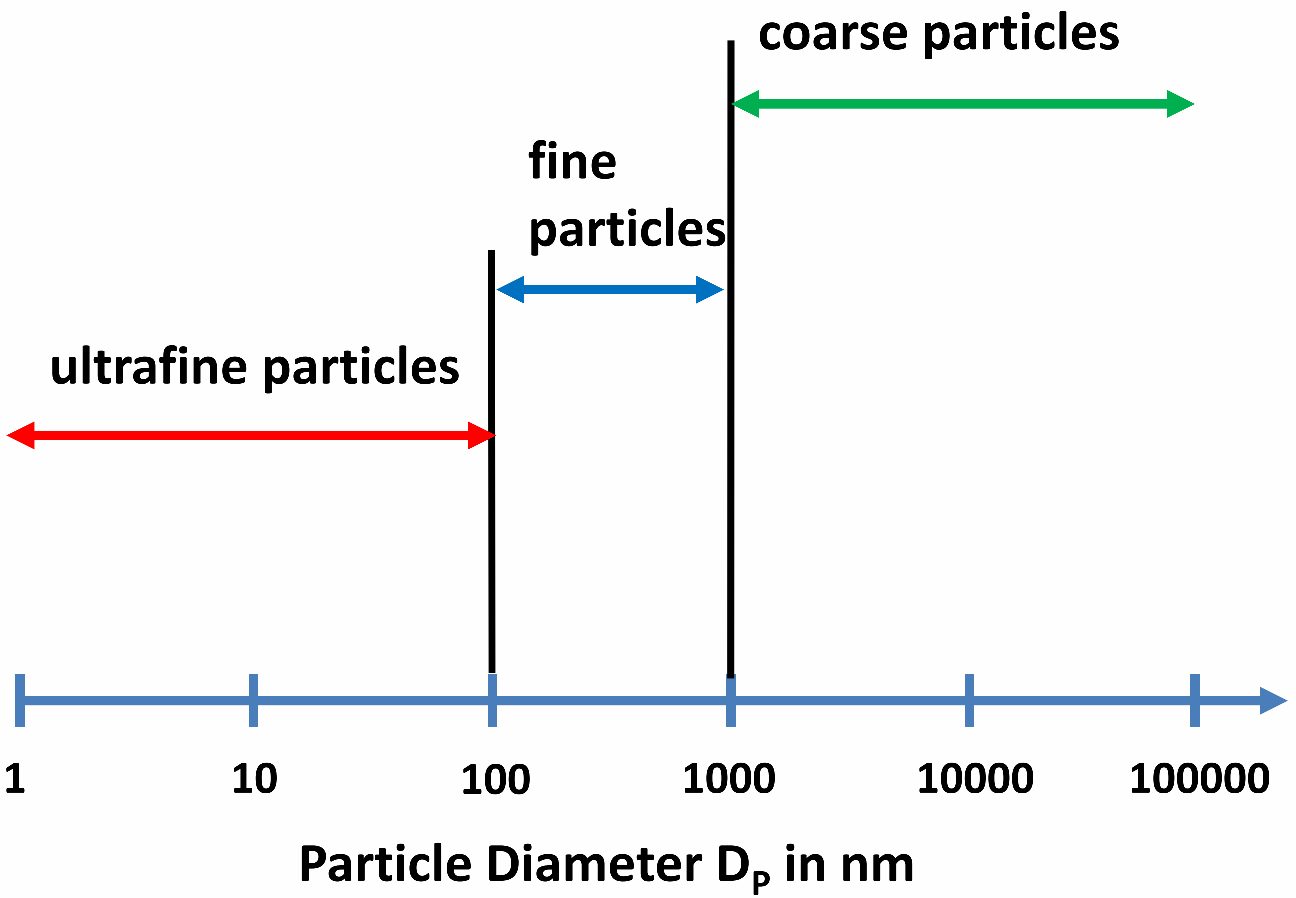
Accumulation mode range	100-1000 nm

Ultrafine Particles

Particles smaller than 100 nm in diameter

Aitken mode range	10-100 nm
Nucleation mode range	1-10 nm

Particle Size Ranges



coarse particles

fine particles

ultrafine particles

Particle Diameter D_P in nm

Particle Size

Definition $1\ \text{nm} < D_P < 100\ \mu\text{m}$

$10^{-9}\ \text{m} < D_P < 10^{-4}\ \text{m}$

Micro-Range	Macro-Range
1 nm particle	0.1 mm tip of a needle
350 nm particle	3.5 cm ping-pong ball
2.5 µm particle	25 cm soccer ball
100 µm particle	10 m balloon

Particle Concentrations

- The particle number concentration is described by the parameter N.
- It is defined by the number of particles per volume unit, and given in #/cm$^{3.}$

Other concentrations:

- Particle surface area concentration	S [$\mu m^2/cm^3$]
- Particle volume concentration	V [$\mu m^3/cm^3$]
- Particle mass concentration	M [$\mu g/m^3$]

- The mass concentration can be calculated from the volume concentration and the particle density $\rho_{P.}$
- The particle density is given in [g/cm^3].

Particle Shape

Aerosol particles are normally non-spherical.

However, particles are often assumed to be spheres for a simpler description and use (equivalent diameter).

Aerosol particles with extreme shapes should not be described as spherical particles.

Examples for non-spherical particles

- Asbestos fibers
- Chain agglomerates

Examples for “spherical particles”

- Droplets
- Fly ash particles
- Inorganic salt particles (crystals)
- Compact particles

Particle Diameter Definitions

Particle Diameter

The particle size is defined either by the diameter, D_P

The diameter is typically given in µm [10^{-6} m] or nm [10^{-9} m]

The diameter is normally defined as equivalent diameter (non-spherical particles are described as spheres).

Particle diameter definitions

Different measurement principals result in different definitions for the particle diameter:

- Stokes (mobility) diameter, $D_{P,St}$
- Optical diameter, $D_{P,Opt}$
- Aerodynamic diameter, $D_{P,Ae}$

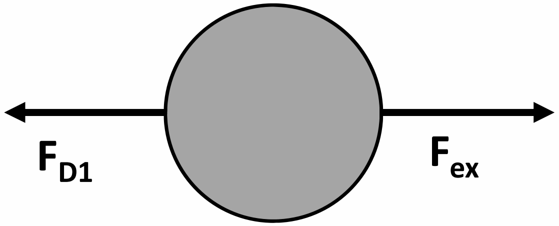
Important is also the volume equivalent diameter, $D_{P,Ve}$

Stokes Diameter (Mobility Diameter)

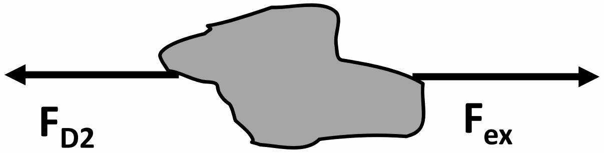
The Stokes diameter is defined for a **uniform particle motion**, where the external force equals the drag force. The motion is independent of the particle density.

$$\boxed{\vec{u}_{\mathrm{P}} = \mathrm{constant}}$$

$$\boxed{\vec{F}_{ex} = \vec{F}_{\mathrm{D}} = \frac{3\pi \cdot \eta \cdot \vec{u}_{\mathrm{P}} \cdot D_{\mathrm{P}}}{C_{\mathrm{C}}}}$$



- For a spherical particle, the Stokes diameter $D_{\mathrm{P1,St}}$ can be determined then by the drag force and the particle velocity.
- In case of a spherical particle, the Stokes diameter is equal the geometric diameter and the volume equivalent diameter $D_{\mathrm{P1,Ve}}$.

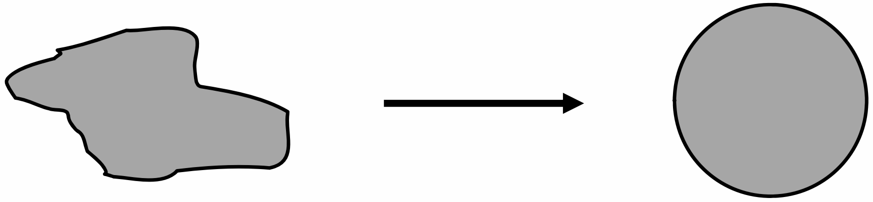


For an irregular particle, the Stokes diameter, if $D_{\mathrm{P2,St}} = D_{\mathrm{P1,St}}$

$$\vec{u}_{P2} / \vec{F}_{\mathrm{D2}} = B_2 = B_1 = \vec{u}_{P1} / \vec{F}_{\mathrm{D1}}$$

The volume equivalent diameter of an irregular particle can be calculated by knowing additionally the dynamic shape factor.

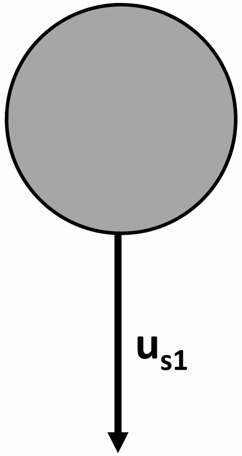
$$\boxed{\vec{F}_{\mathrm{D}} = \frac{3\pi \cdot \eta \cdot \vec{u}_{\mathrm{P}} \cdot D_{\mathrm{P,Ve}}}{C_{\mathrm{C}}} \cdot \chi}$$



The volume equivalent diameter $D_{\mathrm{P2,Ve}} < D_{\mathrm{P1,Ve}}$

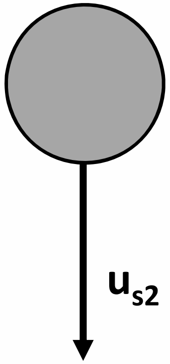
Aerodynamic Diameter

The aerodynamic particle diameter is used when the drag force depends on the particle density such as for sedimentation velocity.



For a certain sedimentation velocity, the aerodynamic particle diameter can be calculated by using $\rho_P = \rho_0 = 1$

$$\boxed{\vec{u}_s = \frac{\rho_P \cdot D_P^2 \cdot C_C \cdot \vec{g}}{18\eta} = \frac{\rho_o \cdot D_{P,Ae}^2 \cdot C_C \cdot \vec{g}}{18\eta}}$$

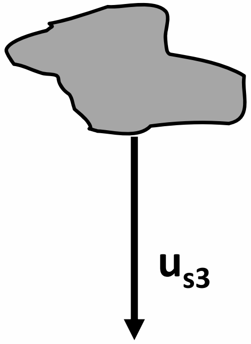


If the particle density is $\rho_P \neq 1$ and the sedimentation velocities are $\vec{u}_{S2} = \vec{u}_{S1}$ the aerodynamic diameters are identical $D_{P2,Ae} = D_{P1,Ae}$

The Stokes diameter can be calculated from the aerodynamic diameter, if the particle density is known.

For a spherical particle with the density $\rho_P > 1$, the Stokes (volume equivalent) diameter is smaller than the aerodynamic particle diameter and can be calculated to:

$$\boxed{D_{P2,St} = D_{P2,Ve} = D_{P1,Ae}\sqrt{\frac{\rho_0}{\rho_P}}}$$

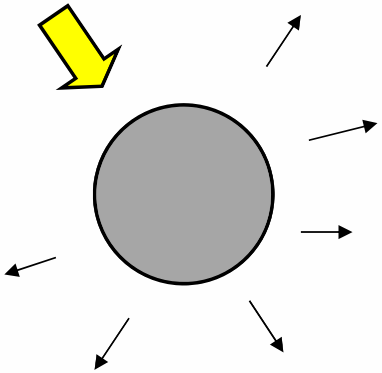


If the particle density is $\rho_{\mathrm{P}} > 1$, the particle is irregular $\chi > 1$, and the sedimentation velocities are $\vec{u}_{\mathrm{S3}} = \vec{u}_{\mathrm{S1}}$, the aerodynamic diameters are identical $D_{\mathrm{P3,Ae}} = D_{\mathrm{P1,Ae}}$.

$$\boxed{D_{\mathrm{P3,Ve}} = D_{\mathrm{P1,Ae}} \sqrt{\frac{\rho_0}{\rho_{\mathrm{P}}} \chi}}$$

Optical Diameter

The optical particle diameter is based on the particle scattering σ_{P}, if the particle is illuminated.

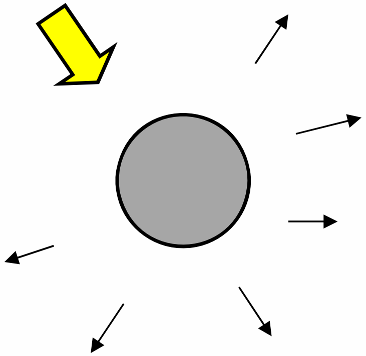


σ_{P}

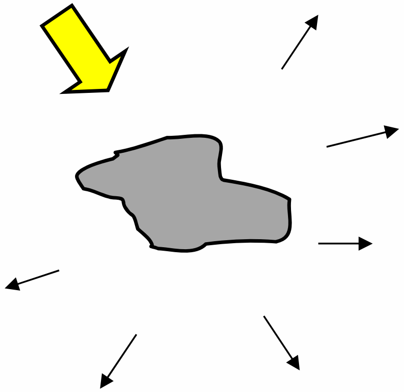
An illuminated spherical particle with a known Stokes diameter (latex particle)and a known refractive index gives a certain particle scattering

The optical diameter of this particle is then calibrated to:

$$\boxed{D_{\mathrm{P1,Latex}} = D_{\mathrm{P1,Opt}} = D_{\mathrm{P1,St}}}$$



An illuminated spherical particle with unknown size and refractive index, but with the same particle scattering $\sigma_{\mathrm{P2}} = \sigma_{\mathrm{P1}}$ has the same optical diameter $D_{\mathrm{P2,Opt}} = D_{\mathrm{P1,Opt}}$.



An illuminated irregular particle with unknown shape and refractive index, but with the same particle scattering $\sigma_{\mathrm{P3}} = \sigma_{\mathrm{P1}}$ has the same optical diameter $D_{\mathrm{P3,Opt}} = D_{\mathrm{P1,Opt}}$.