Definition: Aerosols are suspended particulate matter (liquid or solid) – suspended in a fluid. In terms of atmospheric aerosols, this fluid is air. The Atmospheric Aerosol size distribution extends many orders of magnitude, from nm up to hundreds of microns.

Some Motivations to Study Aerosols

- Health Effects
- Property Damage
- Visibility
- Cloud Formation and Modification
- Climate Effects
- Transport of Nutrients
Amazon in the Wet and Dry Season

**Clear day**
- Visibility ~ ??? km
- $N_{CN} \sim 500 \text{ cm}^{-3}$
- BC ~ 0.2 $\mu$g m$^{-3}$

**Smoke haze**
- Visibility ~ 800 m
- $N_{CN} \sim 10000 \text{ cm}^{-3}$
- BC ~ 7 $\mu$g m$^{-3}$
Scanning Electron Microscopy of Aerosols:

a) Saharan Dust in the US

(Black Circles are filter pores)

b) Smoldering phase Smoke from Amazon

c) Smoke Cluster from Amazon

d) China pollution
Natural biogenic aerosol particles

EPMA photos from Gunther Helas, MPIC
These notes are based on the following references:


- ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences

- Prof. Colin O’Dowd Aerosol Course Presentation
Molecular Mean Free Path: AVG distance between collisions

\[ \lambda = \frac{< c >}{\sqrt{2N\pi\sigma^2} < c >} \]

For air, at 20°C and 1 atm:

\[ \lambda = 0.066 \mu m \]

Typical Size Scales

Note the different scale for each figure.

Adapted From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences
Figure 1. Particle size ranges for aerosols. Reprinted courtesy of SRI International, formerly Stanford Research Institute.
### Figure 1.6 Particle size ranges and definitions for aerosols.

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences

**Measurement Scale**

<table>
<thead>
<tr>
<th>Scale</th>
<th>1 nm</th>
<th>1 µm</th>
<th>100 µm</th>
<th>1 mm</th>
<th>10 mm</th>
<th>1 cm</th>
<th>10 cm</th>
<th>100 cm</th>
<th>1 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angstrom</td>
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<tr>
<td>Nanometer</td>
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<tr>
<td>Submicrometer</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Micrometer</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Coarse</td>
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<td></td>
<td></td>
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<tr>
<td>Ultrafine</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Fine</td>
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<td></td>
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<tr>
<td>Transition</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Continuum Region</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**Designated Size Ranges**

- Free Molecule
- Transition
- Continuum Region

**Aerosol Definitions**

- Fume
- Smoke
- Smog
- Fume
- Dust
- Fog, Mist
- Spray
- Cloud Droplets

**Typical Aerosol Size Ranges**

- Atmospheric Aerosol
- Nuclei
- Accumulation Mode
- Coarse Particle Mode

**Typical Bioaerosol Size Ranges**

- Viruses
- Bacteria
- Pollen
- Fungal Spores

**Sampling Definitions**

- PM-10
- PM-2.5
- Thoracic Particles
- Respirable Particles

**Wavelength of Electromagnetic Radiation**

- X-Rays
- Ultraviolet
- Visible
- Infrared
- Solar

**Other**

- Gas Molecules
- Mean Free Path (STP)
- Red Blood Cell
- Human Hair
- Protein
- Visible to Eye
- Std. Sieve Opening
Aerosol Particle Size Distributions

- Small molecule or atom $\sim 10^{-8}$ cm
- Aerosol particles $\sim 10^{-7}$ cm to 1 cm (including cloud and precipitation droplets, and hail)

Extracted from Seinfeld and Pandis 1998
- Diffusion
- Coagulation
- Sedimentation
- Scrubbing
- Condensation
- Reaction
- Generation
  - Mechanical
  - Chemical

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences
Aerosol Processes in the Atmosphere

Hinds, Aerosol Technology, 1999
Microscopic Measurement of Particle Size

Q: how do you determine this particle’s size?

- **Equivalent sizes of Irregular Particles**
  - Martin’s diameter:
  - Feret’s diameter:
  - Projected area diameter:
Relaxation time $\tau$ for a unit density particle in the air ($p=1$ atm, $T=20^\circ$C)

<table>
<thead>
<tr>
<th>Diameter ($\mu$m)</th>
<th>$v_{TS}=\tau g$</th>
<th>$\tau$ (sec)</th>
<th>Stop Distance ($v_o=1$ m/s)</th>
<th>Stop Distance ($v_o=10$ m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.39 $\mu$m/s</td>
<td>4x10^{-8}</td>
<td>0.04 $\mu$m</td>
<td>4x10^{-4} mm</td>
</tr>
<tr>
<td>0.1</td>
<td>0.93 $\mu$m/s</td>
<td>9.15^{-8}</td>
<td>0.092 $\mu$m</td>
<td>9.15x10^{-4} mm</td>
</tr>
<tr>
<td>0.5</td>
<td>10.1 $\mu$m/s</td>
<td>1.03x10^{-6}</td>
<td>1.03 $\mu$m</td>
<td>0.0103 mm</td>
</tr>
<tr>
<td>1</td>
<td>35 $\mu$m/s</td>
<td>3.57x10^{-6}</td>
<td>3.6 4$\mu$m</td>
<td>0.0357 mm</td>
</tr>
<tr>
<td>5</td>
<td>0.77 mm/s</td>
<td>7.86x10^{-5}</td>
<td>78.6 $\mu$m</td>
<td>0.786 mm</td>
</tr>
<tr>
<td>10</td>
<td>3.03 mm/s</td>
<td>3.09x10^{-4}</td>
<td>309 $\mu$m</td>
<td>3.09 mm</td>
</tr>
<tr>
<td>50</td>
<td>7.47 cm/s</td>
<td>7.62x10^{-3}</td>
<td>7.62 mm</td>
<td>76.2 mm</td>
</tr>
</tbody>
</table>

Note: $1$ m/s = 3.6km/h = 2.2mi/h
Aerodynamic Diameter

- The **Stokes diameter**, \( d_s \), is the diameter of the sphere that has the **same density and settling velocity** as the particle.
- The **aerodynamic diameter**, \( d_a \), is the diameter of the unit density (\( \rho_0 = 1 \text{ g/cm}^3 \)) sphere that has the **same settling velocity** as the particle.

\[
V_{TS} = \frac{\rho_p d_e^2 g}{18\eta X} = \frac{\rho_s d_s^2 g}{18\eta} = \frac{\rho_0 d_a^2 g}{18\eta}
\]

\[
X = \frac{\rho_p}{\rho_0} \left( \frac{d_e}{d_a} \right)^2 = \frac{\rho_p}{\rho_s} \left( \frac{d_e}{d_s} \right)^2
\]

\[
d_a = d_e \sqrt{\frac{\rho_p}{\rho_0 X}} = d_s \sqrt{\frac{\rho_s}{\rho_0}}
\]

Cunningham factor should be included if \( d_p < 1 \mu m \)

Irregular particle
- \( d_e = 5.0 \mu m \)
- \( \rho_p = 4.0 \text{ g/cm}^3 \)
- \( X = 1.36 \)

Stokes’ equivalent sphere
- \( d_s = 4.3 \mu m \)
- \( \rho_p = 4.0 \text{ g/cm}^3 \)

Aerodynamic equivalent sphere
- \( d_e = 8.6 \mu m \)
- \( \rho_p = 1.0 \text{ g/cm}^3 \)

All with \( V_{TS} = 0.22 \text{cm/s} \)
Inertial Impaction

- **Stokes number**: the ratio of the stopping distance of a particle to a characteristic dimension of the obstacle

\[
Stk = \frac{S}{d_c} = \frac{\tau U}{d_c}
\]

- For an impactor

\[
Stk = \frac{\tau U}{D_j / 2} = \frac{\rho p d_p^2 U c}{9 \mu D_j}
\]

Impaction efficiency

\[= f(Stk)\]

Q: Stk << 1? Stk >> 1?

http://plaza.ufl.edu/alallen/cyclone/

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences
\( Stk_{50} \) for 2 impactors

<table>
<thead>
<tr>
<th>Impactor type</th>
<th>( Stk_{50} )</th>
<th>( \sqrt{Stk_{50}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular nozzle</td>
<td>0.24</td>
<td>0.49</td>
</tr>
<tr>
<td>Rectangular nozzle</td>
<td>0.59</td>
<td>0.77</td>
</tr>
</tbody>
</table>

\( 500 < Re_{\text{nozzle throat}} < 3000 \) and \( h'/D_j > 1.5 \)

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences
Cascade Impactor

Aerosol flow In

Clean air out

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences
• Health:
  – Deposition in inhalation system
  – Drug delivery
  – Work place, papermill, mining, pesticide, welding

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences
Respiratory Deposition

• Health hazards caused by inhaled aerosols depend on their chemical composition and on the site at which they deposit within the respiratory system

• Effective medicine delivery by the aerosol route also relies on knowledge of aerosol deposition in our respiratory system

Respiratory System

• **Head airways region** – includes nose, mouth, pharynx and larynx

• **Lung airways or tracheobronchial region** – includes the airways from the trachea to the terminal bronchioles

• **Alveolar region** – gas exchange takes place
Regional Deposition

**FIGURE 11.3** Predicted total and regional deposition for light exercise (nose breathing) based on ICRP deposition model. Average data for males and females.

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences
Alveolar Region

- Particles in the 2 – 10μm range reach the Alveolar region in attenuated numbers
- Alveolar deposition is reduced whenever tracheobronchial and head airway deposition is high

<table>
<thead>
<tr>
<th>Size of Particle</th>
<th>Area of Deposition</th>
<th>Method of Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-30μm</td>
<td>Nose and throat</td>
<td>Impaction</td>
</tr>
<tr>
<td>1-5μm</td>
<td>Trachea and bronchial region</td>
<td>Settling</td>
</tr>
<tr>
<td>1μm or less</td>
<td>Alveolar Region</td>
<td>Diffusion</td>
</tr>
</tbody>
</table>

From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences

Aerosol and Particulate Research Lab
EPA Air Quality Standard for Particulate matter:

http://www.epa.gov/particles/actions.html

EPA classifies particulate matter as two types based on size.

• **Coarse Particulate Matter (PM10)** is less than 10 micrometers in diameter. It primarily comes from road dust, agriculture dust, river beds, construction sites, mining operations, and similar activities.

• **Fine Particulate Matter (PM2.5)** is less than 2.5 micrometers in diameter. PM2.5 is a product of combustion, primarily caused by burning fuels. Examples of PM2.5 sources include power plants, vehicles, wood burning stoves, and wildland fires.

**NEW PARTICULATE MATTER REGULATIONS**

The EPA recently updated the national standards for Particulate Matter. For PM10, the EPA retained the current 24 hour PM10 standard of 150 µg/m3 and eliminated the annual PM10 standard. The EPA increased the stringency of the PM2.5 standard by lowering the previous 24 hour standard of 65 µg/m3 to 35 µg/m3. EPA left the annual PM2.5 standard of 15 µg/m3 in place.
Stacked Filter Unit

- Very low cost
- PM10 and PM2.5
- Trace element analysis
- SEM analysis
- Mass (microbalance)
- Absorption via Reflectance

Nuclepore filter pores 0.4 μm
Nuclepore filter pores 8 μm

47 mm