Particles

- Particle size expressed in microns or micrometers (1 μm = 1/1,000,000 m = 0.00003937 inches)
- Diameters of various particles
- EPA definitions and terminology
- Interaction of particles with the human body
- Interaction of particles with light
- Microscopic images: Sizes and shapes of various air-borne particles

Why 10 μm particle size is important

- Particles < 10 μm are inhalable (can enter the lungs), and are potentially problematic for human health.
- Particles > 10 μm do not get inhaled into the lungs, but get trapped in the nose or throat.
- EPA is concerned with particles less than 10 μm ("coarse particles"), because of their potential effect on the lungs.
- EPA labels these coarse particles as PM10 ("Particulate Matter less than 10 microns"), and lists them among the 7 CAPs (Criteria Air Pollutants) for which the EPA issues NAAQS (National Ambient Air Quality Standards) for healthy air.
**Why 2.5 μm particle size is important**

- Particles < 1.0 μm are submicron particles ($D_p < 1$ μm).
- Natural processes and grinding produce mostly supermicron particles ($D_p > 1$ μm).
- Particles < 1 μm can penetrate really deep into the lungs, all the way into the alvioli, and are potentially very problematic for human health.
- Particles near 1 μm interact most with visible light, since light waves are around 1 μm, and these particles may lead to significant opacity and visibility reduction.

**Why 2.5 μm particle size is important**

- Particles < 2.5 μm are respirable – can penetrate deep into the lungs, and are potentially more problematic for human health than PM10.
- EPA is most concerned with these small particles ("fine particles"), because of their effect on the lungs.
- EPA labels these small particles as PM2.5 ("Particulate Matter less than 2.5 microns" or "fines"), and lists them among the 7 CAPs (Criteria Air Pollutants) for which the EPA issues NAAQS (National Ambient Air Quality Standards) for healthy air.

**Why 1 μm particle size is important**

- Combustion (burning) produces mostly submicron particles ($D_p < 1$ μm).
- Natural processes and grinding produce mostly supermicron particles ($D_p > 1$ μm).
- Particles < 1 μm can penetrate really deep into the lungs, all the way into the alvioli, and are potentially very problematic for human health.
- Particles near 1 μm interact most with visible light, since light waves are around 1 μm, and these particles may lead to significant opacity and visibility reduction.

**The Electromagnetic Spectrum**

<table>
<thead>
<tr>
<th>Wavelength in microns (μm)</th>
<th>Waveband</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 to 0.7 μm</td>
<td>UV</td>
</tr>
<tr>
<td>0.7 to 1.5 μm</td>
<td>Visible</td>
</tr>
<tr>
<td>1.5 to 3.0 μm</td>
<td>IR</td>
</tr>
<tr>
<td>3.0 to 30 μm</td>
<td>Microwaves</td>
</tr>
</tbody>
</table>

**We see the colors of the rainbow with our eyes, due to the refraction of light rays through raindrops.**

- Red – long wavelength, less refraction
- Violet – short wavelength, more refraction

**How Small of a Particle Can We See?**

- Estimates vary, but range from $D_p = 20$ to 100 μm as the smallest object a healthy naked human eye can see.
- On average, most people can distinguish objects down to about 70 μm, about the size of a single strand of hair.
- However, if the object is a glowing particle or a particle that scatters light and is seen by the eye as a source of light (e.g. bubbles, transparent particles that scatter sunlight, etc.), a healthy human eye can see down to about $D_p = 10$ μm.
- Many air pollution particles scatter light, so 10 μm is a useful benchmark: The naked eye can see individual air pollution particles down to about 10 μm.
- However, we can see clouds of smaller (even submicron!) particles because of blockage and scattering of light.
The human respiratory system

- The tracheobronchial region
  - Also called the **conducting airway**
  - The trachea divides into two primary bronchi (one to each lung)
  - Each primary bronchus divides again and again at least 20 times – the **bronchial tree**
  - Bronchi move air in and out of the lung, but do not exchange gases with the blood
  - Bronchi are lined with **mucus** and hair-like organs called **cilia** that expel particles up and out of the trachea

- The pulmonary region
  - Also called the **respiratory airspace**
  - At the end of each bronchiole are clusters of air sacs called **alveoli**
  - Alveoli contain thin membranes in which air and other gases are exchanged with the blood
  - Total useful surface area of alveoli is over 100 m² – about half the surface of a tennis court (261 m²)!
  - Alveoli do not have cilia, but instead remove particles through white blood cells called **macrophage**

Cilia beat to transport particles from the lungs

Close-up view of cilia in a bronchial tube
Cross-section of a human lung – looks like a sponge

Cross-section of a human lung at higher magnification

Close-up view of alveoli and pores in the alveoli membrane

Cross-section of a healthy human lung

Example of a human lung with accumulated particles

ANDERSEN SAMPLERS: Simulates Human Respiratory System

How particles of various sizes penetrate into the human respiratory system

- Inhalable coarse particles (PM10–PM2.5) get trapped in the tracheobronchial region; are expelled by cilia.
- Supermicron fine particles (PM2.5, but $D_p > 1\, \mu m$) can penetrate to the smallest bronchi; are expelled by cilia.
- Submicron particles ($D_p < 1\, \mu m$) can enter the alveoli; macrophage must remove them.

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Particle sizes and shapes

The PARTICLE ATLAS
Edition Two

An encyclopedia of techniques for small particle identification

Volume IV
The Particle Analyst’s Handbook

Walter C. M. Stone
John Gunther Delly

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2/28/2014

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Human hair
(The hairs shown here range between 50 and 150 μm in diameter, and are smooth and straight)

Human hair fragments after shaving
(also some skin cells and dirt)

Asbestos
(lots of hairy fibrils, which are < 1 μm diameter)

Fiber glass
(straight smooth cylinders, 8 μm diameter)

Fiber glass dust
(irregular shapes, 10 to 25 μm long)

This is what you breathe when working in your attic!

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**22. Ragweed pollen (Ambrosia ssp.)**

This allergen pollen is probably the one most frequently reported in pollen season surveys. It is isoeucos, generally spherical (often spherical) and covered with short spines. The spores range from 30 to 50 μm in diameter, with a width of 0.3-0.4 μm. The pollen grains are usually 1-3 μm high and about 1.5-3 μm apart. The grains have three bars: 0.5-1.5 μm and three alveolar pores about 0.6-1.0 μm wide. The spores have been stained with oil red. The pollen is about 18 to 20 μm in diameter, spherical.

**10 μm**

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**33. Mold (Rhizopus)**

This mold has spores that are spherical with a diameter of about 18-20 μm, surrounded by short spines. The spores are 30-50 μm in diameter, with a width of 0.3-0.4 μm. The pollen grains are usually 1-3 μm high and about 1.5-3 μm apart. The grains have three bars: 0.5-1.5 μm and three alveolar pores about 0.6-1.0 μm wide. The spores have been stained with oil red. The pollen is about 18 to 20 μm in diameter, spherical.

**10 μm**

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**385. Deodorant spray powder (talc)**

This sample is typical of deodorant spray powders. It consists of a number of small, white, spherical crystals. The crystals are about 10 to 20 μm in diameter, with a width of 0.3-0.4 μm. The pollen grains are usually 1-3 μm high and about 1.5-3 μm apart. The grains have three bars: 0.5-1.5 μm and three alveolar pores about 0.6-1.0 μm wide. The spores have been stained with oil red. The pollen is about 18 to 20 μm in diameter, spherical.

**10 μm**

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**562. Coal flyash, underfeed stoker**

The combustion products from underfeed coal stoker are characterized by irregular shapes, lots of unburned fuel, impurities, and ash. The particles range from 1 to 150 μm in diameter. The ash from underfeed coal stoker is characterized by irregular shapes, lots of unburned fuel, impurities, and ash. The particles range from 1 to 150 μm in diameter.

**10 μm**

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**379. Ammonium sulfate (NH₄SO₄)**

Ammonium sulfate, (NH₄)₂SO₄, is a transparent, colorless crystal when viewed under transmitted light. It usually has a slightly rough surface texture. Well-formed crystals range from 10 to 100 μm in diameter, with a width of 0.3-0.4 μm. The pollen grains are usually 1-3 μm high and about 1.5-3 μm apart. The grains have three bars: 0.5-1.5 μm and three alveolar pores about 0.6-1.0 μm wide. The spores have been stained with oil red. The pollen is about 18 to 20 μm in diameter, spherical.

**10 μm**

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**381. Electric arc furnace dust**

Electric arc furnace dust is characterized by irregular shapes, lots of unburned fuel, impurities, and ash. The particles range from 1 to 150 μm in diameter. The ash from underfeed coal stoker is characterized by irregular shapes, lots of unburned fuel, impurities, and ash. The particles range from 1 to 150 μm in diameter.

**10 μm**