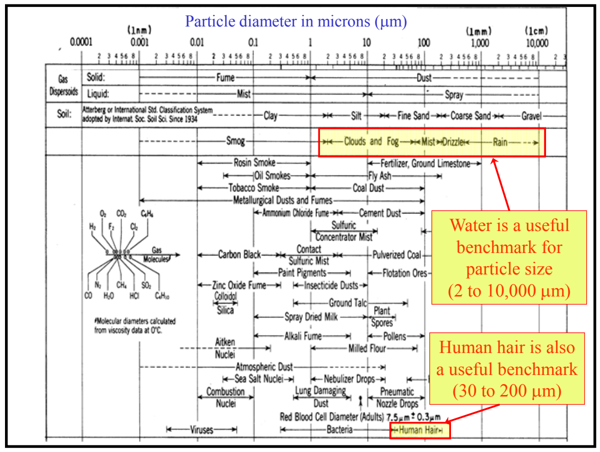
Particles

- 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



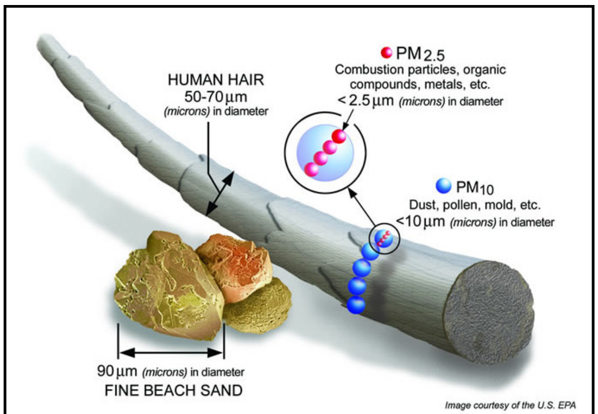
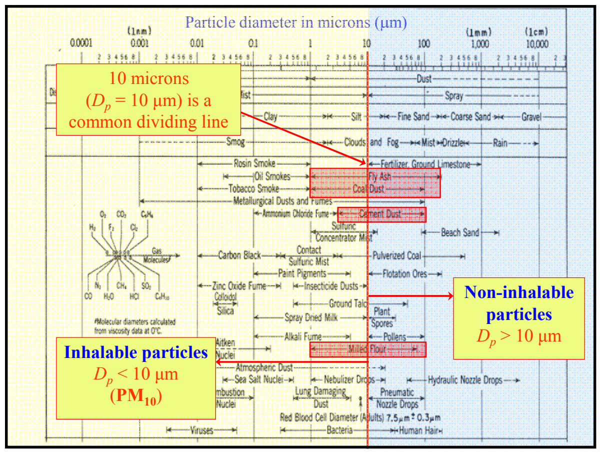
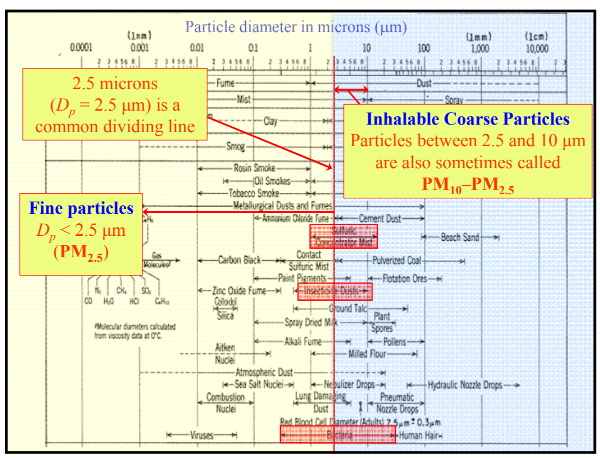


Photo from EPA website, http://www.epa.gov/pm/basic.html.



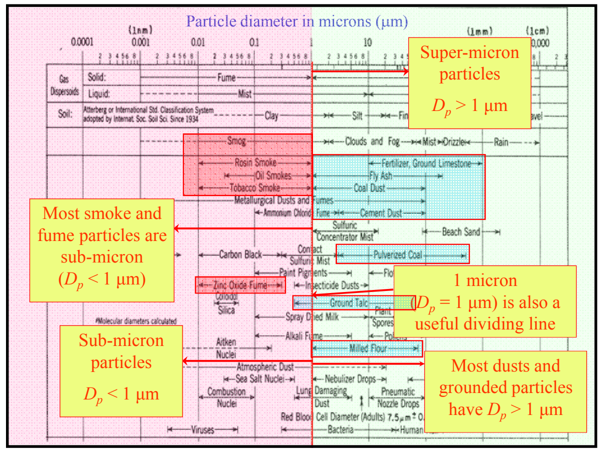
Why 10 µm particle size is important

- 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 **PM_{10}** (**"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

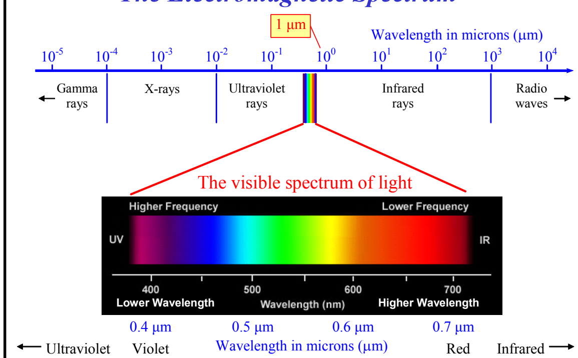
- Particles < 2.5 µm are ***respirable*** – can penetrate deep into the lungs, and are potentially more problematic for human health than PM_{10}.
- EPA is most concerned with these small particles ("***fine particles***"), because of their effect on the lungs.
- EPA labels these small particles as $\mathbf{PM_{2.5}}$ ("**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



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

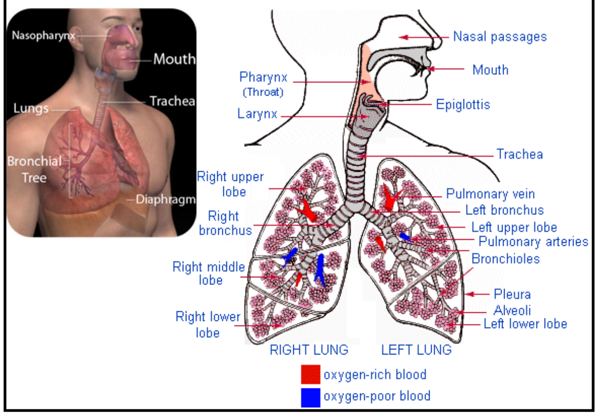
Red – long wavelength, less refraction

Violet – short wavelength, more refraction

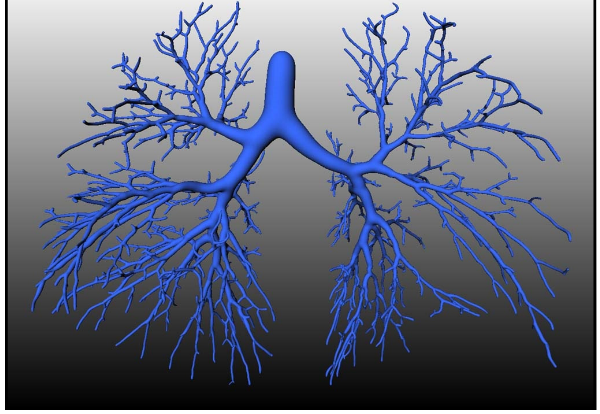
How Small of a Particle Can We See?

- 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, it 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

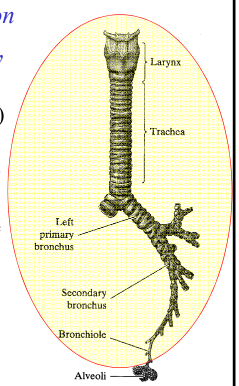


The bronchial tree

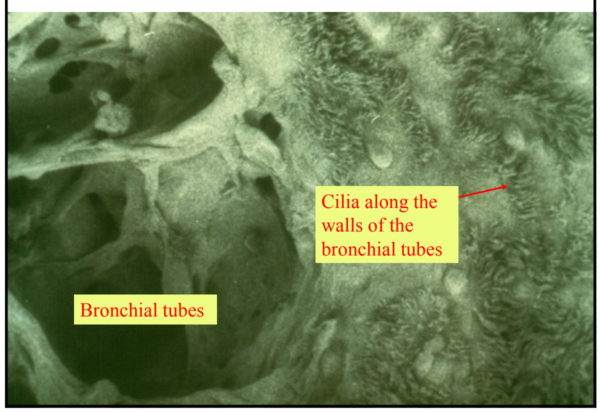


The tracheobronchial region

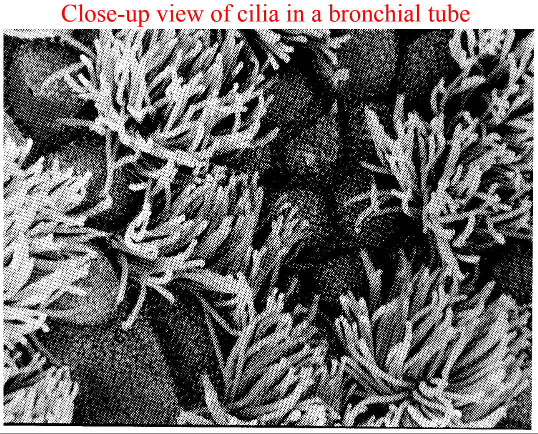
- Also called the ***conducting airway***
- The trachea divides into two primary bronchi (one to each lung)
- Each primary bronchus divides again and again at least 20 times – the ***bronchial tree***
- Bronchi move air in and out of the lung, but do not exchange gases with the blood
- Bronchi are lined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



Cilia beat to transport particles from the lungs

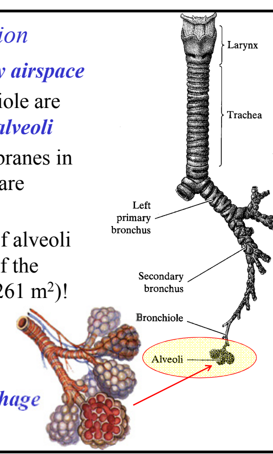


Close-up view of cilia in a bronchial tube

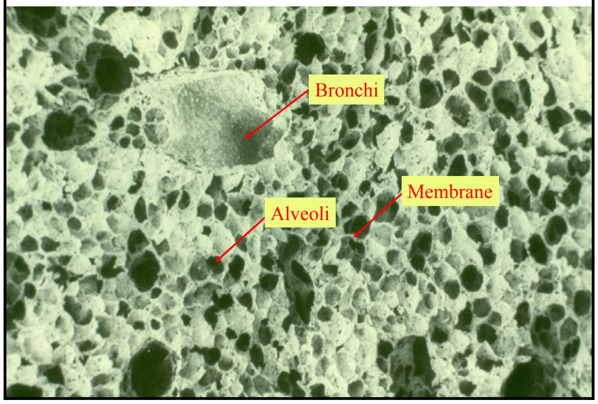


The pulmonary region

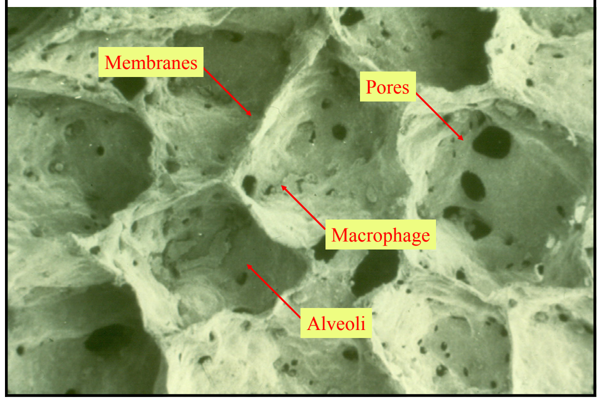
- Also called the ***respiratory airspace***
- At the end of each bronchiole are clusters of air sacs called ***alveoli***
- Alveoli contain thin membranes in which air and other gases are exchanged with the blood
- Total useful surface area of alveoli is over 100 m^2 – about half the surface of a tennis court (261 m^2)!
- Alveoli do not have cilia, but instead remove particles through white blood cells called ***macrophage***

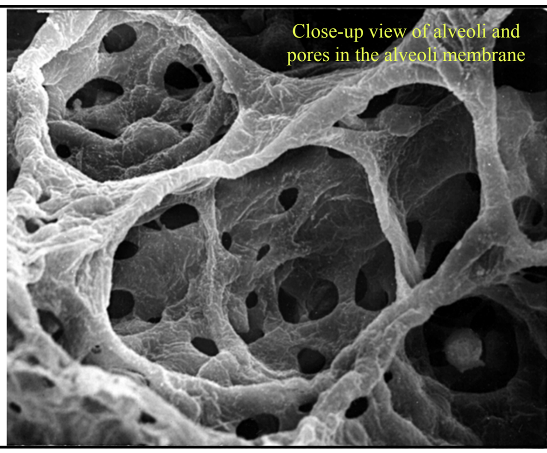


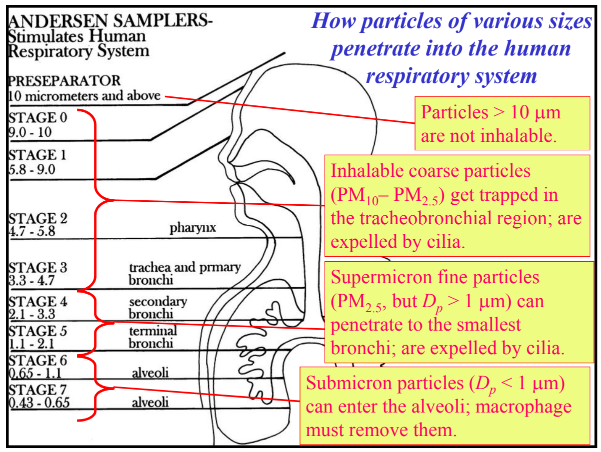
Cross-section of a human lung – looks like a sponge



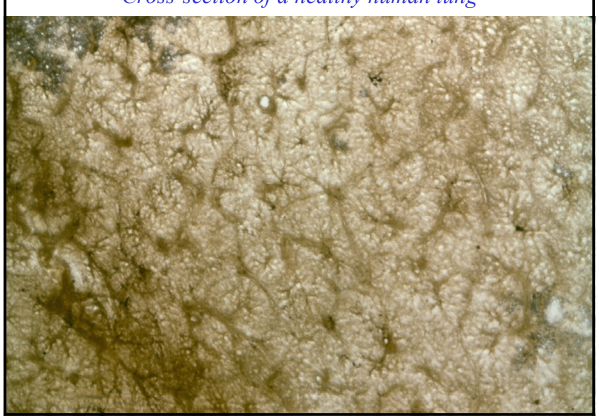
Cross-section of a human lung at higher magnification



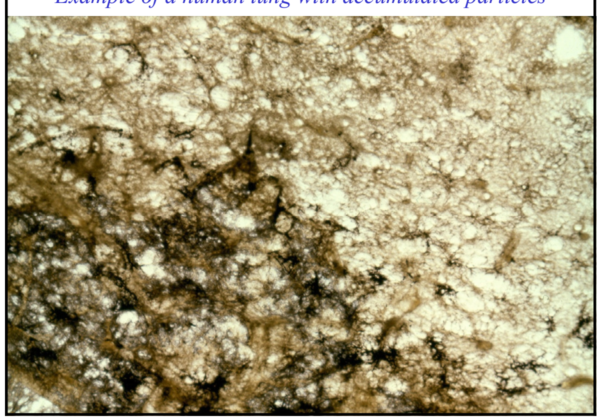




Cross-section of a healthy human lung



Example of a human lung with accumulated particles



Particle sizes and shapes

From:

The PARTICLE ATLAS

Edition Two

An encyclopedia of techniques for small particle identification

Volume IV
The Particle Analyst's Handbook

Walter C. McCrone
John Gustav Delly

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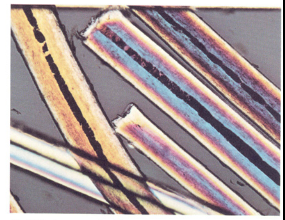
49 HUMAN HAIR (CAUCASIAN)

9:001001 25:011001

Human hairs may be transparent to almost opaque, with circular or oval cross sections (001001, 011001). The scalloped, overlapping scales do not protrude from the shaft very much. The cuticle is usually six to eight scale layers thick and covers the entire fiber. The central canal, or medulla, which is opaque if filled with air, may be as much as one third the width of the hair and may be continuous, fragmented or absent. Medullae of larger hairs tend to be more continuous. Pigments may be absent to considerable. Human hair ranges from 50 to 150 μm in diameter. Animal hairs are usually less than half the diameter of the finest human hair although the guard hairs are more than twice that of the coarsest human hair. Human hair types vary, depending on age, race, sex and the portion of the body concerned. The indices are about 1.542 (crosswise) and 1.554 (lengthwise); (+) 0.012. Extinction between crossed polars is usually regular and parallel along the length of the hair, but from some parts of the body, hairs are more irregular in cross section (bumpy) and lack uniform extinction ("polycrystalline"). The mean range of density of nonmedullated hairs is about 1.335 to 1.348 g/cm³.



49 Slightly uncrossed polars 125X

10 μm ⟶ •

Human hair
(The hairs shown here range between 50 and150 μm in diameter, and are smooth and straight)

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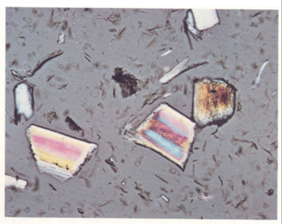
50 HUMAN HAIR (ELECTRIC RAZOR)

9:001001 10:001010 25:011001 26:011010

The identifying characteristics of the hair in this sample are identical to those described above (*49*); the identifying characteristics of the skin cells are those described under *epithelial cells* (*3*). The electric razor is indicated by the short (70–130 μm) lengths of hair cut at an angle of about 30° (20–45°). The cut ends are not particularly clean and may be quite jagged. Hairs shaved in opposite directions on successive days result in trapezoidal fragments. Thin, fibrous fragments may appear to be isotropic because of the low birefringence of hair. Hairs cut with safety razors show smoother, clean-cut ends, including some which are concave. There are also a greater variety of cutting angles shown. About 20% of this electric razor sample consists of skin cells. Finally, hair samples from safety razors consist of about 50% skin cells (000010, 010010).



50 Slightly uncrossed polars 125X

10 μm ⟶ •

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

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122 ASBESTOS (CHRYSOTILE), $Mg_3Si_2O_5(OH)_4$

9:001001

This sample includes bands of straight, parallel fibrils with nonperiodic crimps, wavy bands of fibrils and single, randomly twisted fibrils. The colorless, transparent, cylindrical fibrils (the bands are translucent) are less than 1 μm in diameter and have smooth surfaces. Chrysotile is monoclinic; its indices are 1.529–1.559 (α), 1.530–1.564 (β), 1.537–1.567 (γ parallel to fiber length); (+) 0.004–0.016; 2V cannot be observed. The fibers show parallel extinction and have a positive sign of elongation. The low α index distinguishes chrysotile from other asbestos forms such as *crocidolite* (*123*) and *anthophyllite* (*121*). Probably the best key to the identification of chrysotile is its low refractive index. The specific gravity is 2.2; the hardness ranges from 2.5 to 4.

10 μm ⟶ •

122 Slightly uncrossed polars 125X

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

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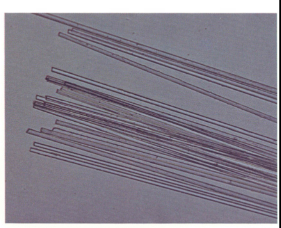
106 FIBER GLASS

1:000001

These are transparent, colorless, continuous, isotropic cylinders, almost always smooth and regular. The ends usually show a clean transverse or diagonal break, but they are sometimes chipped, just like the broken ends of macroscopic glass rods. The cross sections of the fibers are perfectly round, 8 μm in diameter. The index is usually around 1.55 although it varies widely, normally about 1.47 for borosilicate and above 1.52 for soft glass.

10 μm ⟶ •



106 Slightly uncrossed polars 160X

Fiber glass
(straight smooth cylinders, 8 μm diameter)

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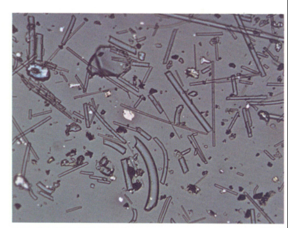
107 GLASS WOOL

0:000000 1:000001

This is a settled dust sample from an area in which fine glass wool is applied as insulation between the outer jacket and inner container of water-heater tanks. Ninety-five percent of the sample is glass wool: transparent, colorless, isotropic rods, commas, dumbbells, U's, T's and completely amorphous globs of glass. The globs are all rounded; the rods are both uniform in diameter and tapering (both regularly and nonuniformly). The straight and "blobular" rods average 10 μm (3–15 μm) wide and 25 μm (5–1000 μm) long. The index is about 1.51 (000001, 000000).

Other particles in this settled-dust sample include *cotton* (*59*) and *paper fibers* (*70–74*), as well as *quartz* (*183*), *calcite* (*133*) and *combustion products* (*551–579*).

10 μm ⟶ •



107 Slightly uncrossed polars 160X

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

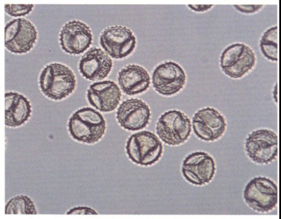
This is what you breathe when working in your attic!

22 RAGWEED POLLEN (*Ambrosia sp.*)

16:010000

This allergenic pollen is probably the one most frequently reported in pollen count surveys. It is isotropic, generally spherical (oblate spheroidal) and covered with short spines. The transparent to translucent grains average 18.0 × 19.3 μm (16.2–20.4 × 17.9–21.3 μm). The pale yellow skin, or exine, has a granular surface. The spines are about 0.5 μm high and about 1.7–3.4 μm apart. The grains have three furrows 4.5 × 1.6 μm and three elliptical pores 4.0 × 1.6 μm, one in each furrow. This sample is mounted both in a nonaqueous medium (*22A*) and in an aqueous medium (*22B*). The grains are apt to show one or two depressions when mounted in Aroclor®; this gives them a pinched effect. The grains in *22B* have been stained with acid fuchsin.

10 µm →



22A Plane polarized light 500X

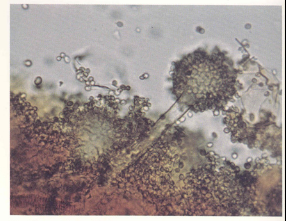
Ragweed pollen
(about 18 to 20 µm diameter, spherical)

33 MOLD (fungus)

0:000000 1:000001 3:000011 16:010000

This mold from pecans is included as typical of many sporulating molds. The cottony masses (mycelium) usually thought of as mold are made up of individual fibers, or hyphae, of three kinds. Some (stolons) grow horizontally; these send others (rhizoids) into the substratum; other hyphae (sporangiophores) grow upright. The ends of the sporangiophores develop enlarged spore heads, each bearing hundreds of asexual spores. The sporangiophores are transparent, colorless, isotropic, smooth cylinders or twisted ribbons, 10–12 μm wide (000001, 000011). The spores are transparent, colorless, isotropic, smooth, oval bodies, 3–5 μm across (000000). The spore heads, about 40 μm across, are covered with spores. When all of these have been discharged, the barren head is seen to be almost spherical or mushroom-shaped. It is transparent, orange and isotropic (010000).

10 µm →



33 Plane polarized light 400X

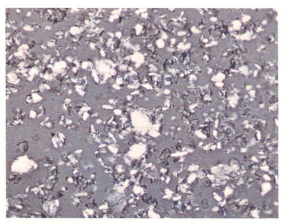
Mold
(spherical heads ≈ 40 µm diameter,
tails about ≈ 10 µm diameter, and spores ≈ 4 µm)

585 DEODORANT SPRAY POWDER

0:000000 10:001010

This sample is typical of deodorant spray powders. About 70–75% of the sample consists of birefringent flakes of talc (see *talc, 198*) (001010). The 3–5% limestone (see *calcite, 133*) in this sample is an impurity, probably accompanying the talc. About 10% consists of magnesium stearate or zinc stearate added to aid adherence and assist waterproofing. This component is colorless, transparent, isotropic and rounded (000000). Although this sample does not contain it, zinc oxide is sometimes added to 5% as an active ingredient. Hexachlorophene, usually less than 1%, may also be added. Emulsifiers and surfactants are also usually present to 3–5%. This sample has, in addition, encapsulated fragrance in the form of 6–14 μm transparent, colorless, isotropic, gelatinous spheres with entrapped air. A valve lubricant is also added.

10 µm →



585 Slightly uncrossed polars 300X

Deodorant spray powder (talc)
(various diameters > 1 µm)

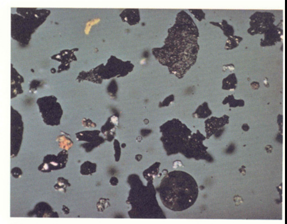
563 COAL FLYASH, UNDERFEED STOKER

0:000000 16:010000 32:100000

The flyash from an underfeed stoker-fired boiler will usually contain particles of unburned fuel and coked fuel (100000) as well as unfused and fused ash. In addition to the few unburned and coked coal particles, there are:

1. The particles of unfused ash (010000) are gray to orange. They are translucent to opaque by transmitted light due to air inclusions. The refractive index is between 1.52 and 1.65.
2. The particles of fused ash (000000, 010000) range in color from colorless to a dingy greenish-brown. They are spherical and may be transparent to translucent due to air inclusions. The refractive index ranges from about 1.52 to about 1.58.

10 µm →



563 Top light, slightly uncrossed polars 125X

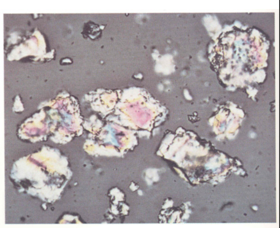
Combustion products from underfeed coal stoker
(1 to 150 µm dia., irregular shapes, lots of unburned
fuel, impurities, and ash)

279 AMMONIUM SULFATE, $(NH_4)_2SO_4$

8:001000

Ammonium sulfate, $(NH_4)_2SO_4$, is a transparent, colorless crystal when viewed using transmitted light. It usually has a slightly rough surface texture. Well-formed crystals are equant to prismatic and occasionally slightly flattened; the fracture is uneven and the cleavage is good. Ammonium sulfate is orthorhombic; 1.5209 (α), 1.5209 (β), 1.5330 (γ); (+) 0.0121. The crystals have a specific gravity of 1.769, and they decompose at 235°C.

10 µm →



279 Slightly uncrossed polars 125X

Ammonium sulfate (sometimes from power plants)
(very uneven irregular shapes, 10 to 100 µm or larger)

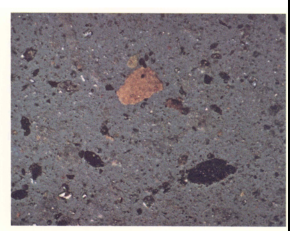
381 ELECTRIC FURNACE DUST

0:000000 4:000100 16:010000 20:010100
32:100000

This sample has several major components:

1. Fine, opaque, gray-black powder in spheres less than 2 μm across, often coating other particles (100000). Besides the free particles, agglomerates seem to be trapped in a translucent, colorless to grayish yellow, isotropic, rounded, irregular matrix. The particle indices are about 1.66 (000100, 010100). Many are so densely packed that they appear completely opaque; their outlines are granular, and the surfaces are foamy to slightly rough (100000).
2. Transparent, colorless and brown to gray, isotropic spheres of fused ash averaging 5 μm in diameter (3–50 μm). The index is about 1.58. Many contain trapped gases (000000, 010000).
3. Black, opaque spheres of magnetic *iron* (*165*) (100000).

10 µm →



381 Slightly uncrossed polars 125X

Electric arc furnace dust
(individual particles < 2 µm diameter, but coagulate
into much larger irregular shapes)