unisanté

Physico-chemicals (particles and fibers) Properties

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Definitions

Aerosol:

suspension of liquid or solid particles in a gas having a sedimentation speed below 25 cm/s

Dusts:

suspension of solid particles in a gas, ranging in size from 1 to about 100 microns.

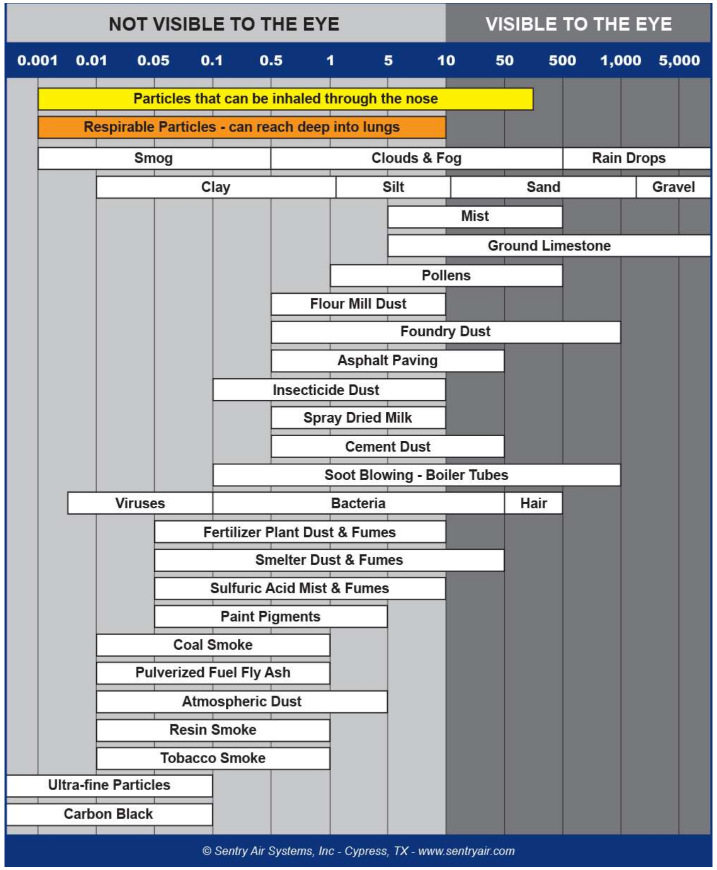
Fumes:

suspension of solid particles, ranging in size from 0.001 to 1 micron, usually formed by condensation (e.g. incomplete combustion)

Mists:

suspension of liquid particles in a gas, having a size below 10 microns

Aerosol types and size



Wide range of

- *Shape, size, composition*

Particles are <u>not</u> compared according to their physical diameter

Aerosols

Source of emission

Any process involving: mechanical

- Abrasion
- Handling of powders
- Handling of fluids (boiling, nebulization…)
- Combustion

…Produces aerosols

Industrial process

- Construction, agriculture, metallurgy, waste processing, textile industry, office work…

Home appliances

- Cooking, candles, gardening…

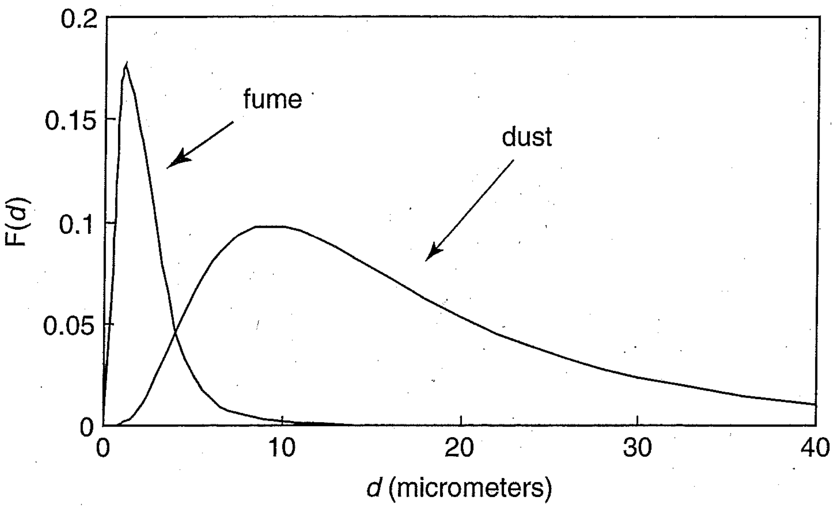
Particles

Size distribution

- Seldom mono-dispersed, generally a population of poly-dispersed particles.

- Typical mass distribution (log-normal)

$$m_p(D) = \frac{M}{D\sqrt{2\pi} \cdot \ln\sigma_g} \exp\left[-\frac{(\ln D - \ln D_{50})^2}{2(\ln\sigma_g)^2} \right]$$



m_p: massic fraction

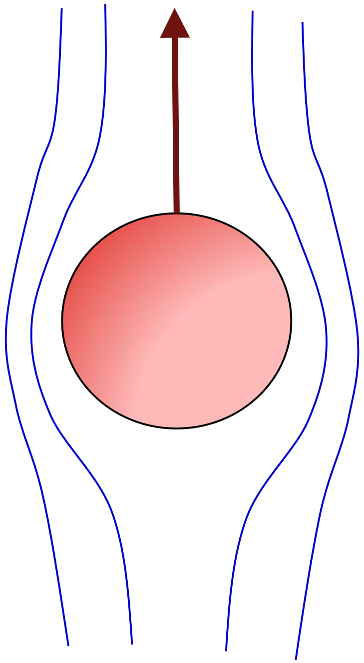
D : particles diameter

D_{50} : median diameter

σ_g : standard geometric deviation
mono-dispersed (σ_g =1),
poly-dispersed (σ_g =2-3)

Aerosol mechanics

Drag force



A spherical particle in a moving fluid endures a drag force (1/3 pressure force, 2/3 friction) corresponding to:

$$W = -6\pi r \eta v$$

For Re < 1, 1-100 μm (Stockes regimes)

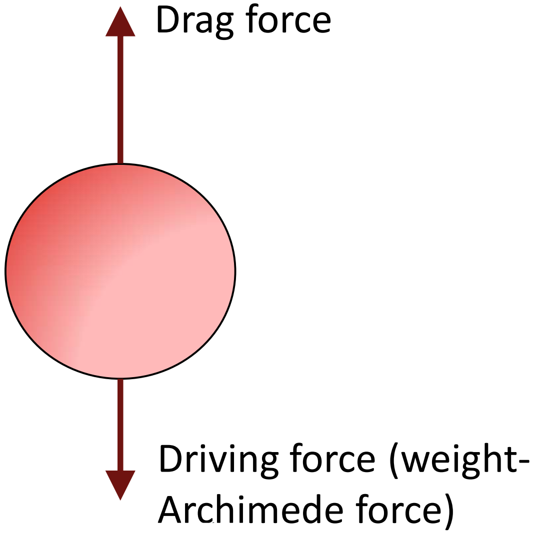
η = dynamic viscosity, air = 1.82 10-5 N s m^{-2}
r = radius (m)
v = speed (m s^{-1})

$$Re = \eta \rho v D$$

Aerosol mechanics

Terminal velocity

Equilibrium (constant velocity) is attained when the drag force equals the driving force.
This is the terminal velocity of a falling particle.



$$W = -6\pi r \eta v$$

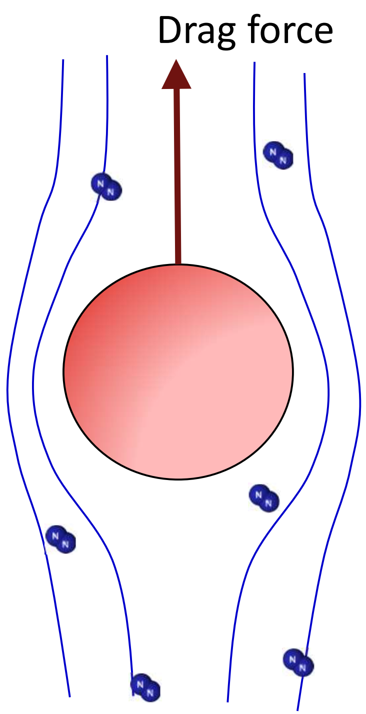
η = dynamic viscosity
r = radius (m)
v = terminal velocity (m s^{-1})
ρ= density (kg m^{-3})
g = ground acceleration

$$v = \frac{2}{9}\frac{(\rho_{sph} - \rho_{air})}{\eta} g r^2$$

$$P - A = 4/3 \cdot \pi r^3 (\rho_{sph} - \rho_{air}) \cdot g$$

Aerosol mechanism – Slip effect

Slip effect



Contact between particles and air is not a continuum. Small particles (<15 um) slips in vacuum between collision with the gas molecules

- The slip correction factor better predicts the observed sedimentation increase
- Cunningham slip correction factor
- significant for D < 15 um
- *Brownian motion to be taken into account for submicron particles*

Aerosol mechanics

Terminal velocity

Various expressions of the terminal velocity, according to the particle diameter

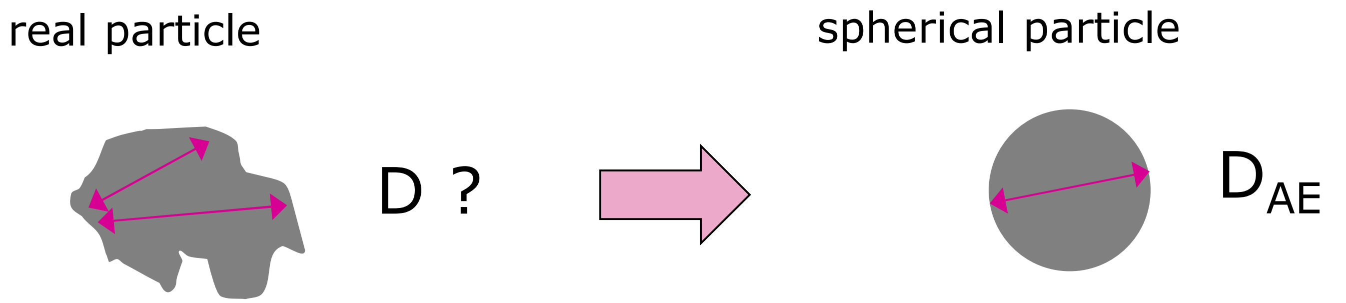
Diamètre	***Modèle physique***
> 200 μm	Pesanteur $v = \sqrt{2gh}$
1 - 100 μm	Stokes $v = \frac{2}{9}\frac{(\rho_{sph} - \rho_{air})}{\eta} g r^2$
0.1 - 1 μm	Correction de Cunningham $V = V_{Stokes}\left(1 + 0.85\,\frac{\ell}{r}\right)$
0.001 - 0.1 μm	Mouvement Brownien rms="root mean square" $V_{rms} = \sqrt{\frac{3RT}{Na \cdot m}}$

sedimentation increases because of the slip correction factor

N_a : nb of Avogadro
rms: root mean square
m : mass
ℓ : mean free path

Aerodynamic diameter

Equivalent diameter

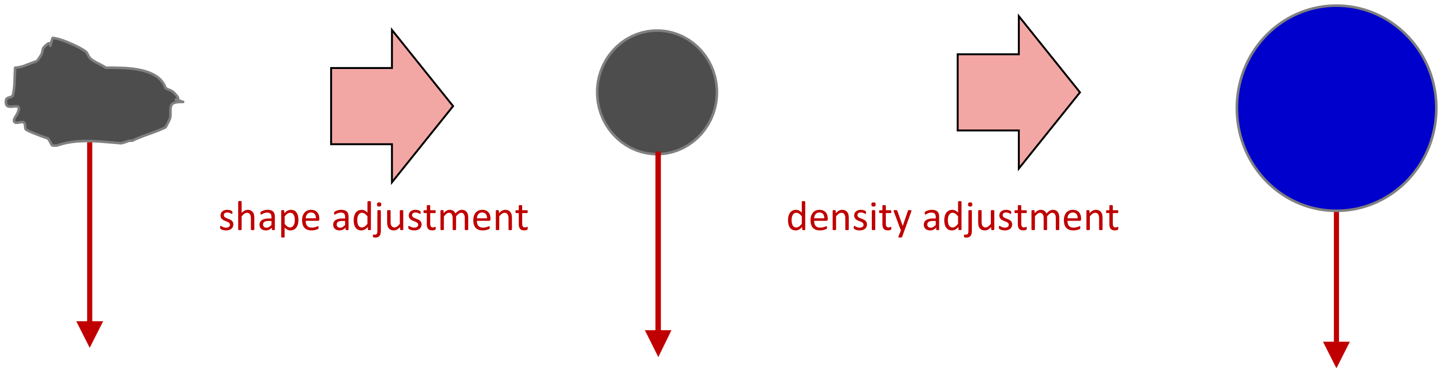


The aerodynamic diameter D_{ae} is the diameter of a spherical particle of density 1 g/cm^3 (idem water), which has the same terminal velocity as the particle of interest.

Same dynamic behavior !

Aerodynamic diameter

Example



Aerodynamic diameter

Dynamic shape factor

For particles within the 1-10 μm range, aerodynamic diameter can be expressed as:

$$D_{AE} = D \cdot (d/F)^{1/2}$$

D = physical diameter
d = density (-), relative to water
F= dynamic form factor

Shape	Dynamic shape factor
sphere	1.0
cube	1.08
sphere aggregates	1.15
Quartz dust	1.36
talc particles (platelets)	2.04
fibres	>>1.0

Dynamic shape factor for different particle morphologies

Case study

Stone cutting

Mr Red works on the renovation of historic monuments as a stonemason. He frequently works with rocks containing crystalline silica. When he cuts stones, he produces a lot of dust.

Question (3.1a)

What is the sedimentation rate in cm per hour of quartz particles with an average physical diameter of 1.75 µµm and a density of 2.65 ?

Case-study solution

Question 3.1a

For this particle Size, we use Stoke's equation

Stokes $\mathbf{v = \frac{2}{9}\frac{(\rho_{sph} - \rho_{air})}{\eta} g r^2}$

η = viscosity, air = 1.82 10^{-5} N s m^{-2}
ρ = density (kg m^{-3})
for air ρ air = 1.20 kg m $^{-3}$
for quartz = ρ quartz = 2'650 kg m^{-3}
ρ quartz - ρ air = 2'648.8 kg m^{-3}
g = 9.81 m s^{-2}

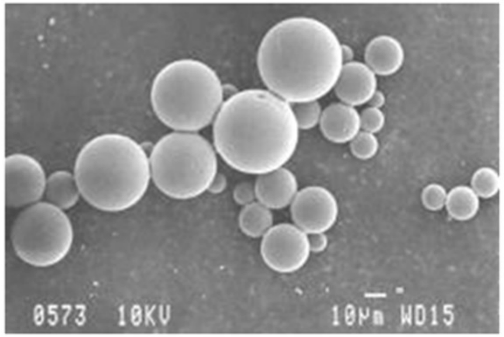
to calculate the falling speed of the particle, we must use its aerodynamic diameter and not its physical diameter.
With a form factor F of 1.36 for quartz particles and using the density of water to find the equivalent diameter, we get:

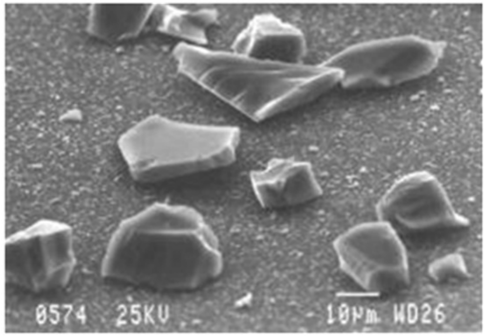
D_{AE} = 2.4m m
r = 2.4/2 = 1.2 10^{-6} m

The terminal velocity becomes:
v = 4.6 10^{-4} m/s

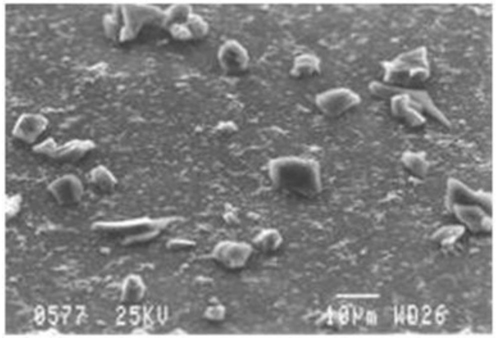
Particles sizes and shapes

Size and shape





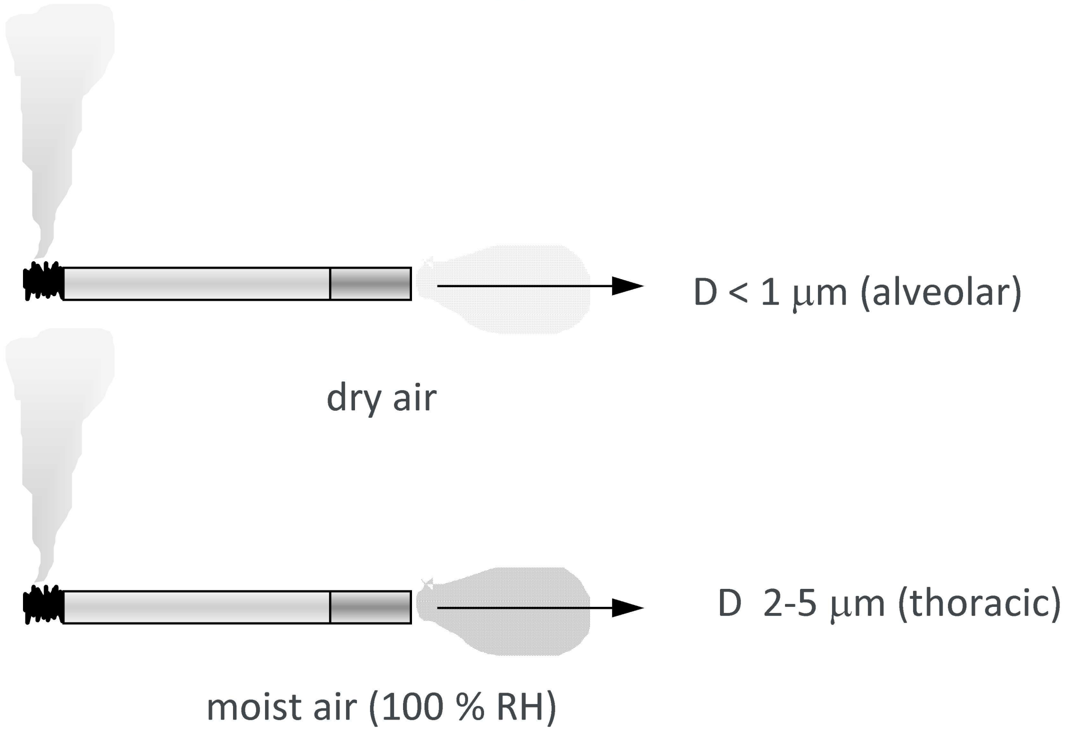
- Size and shape is dependent on:
  - chemical nature, mechanical properties…
  - formation process, separation energy…



Shape and size will affect toxicology through various mechanisms: inhalation, deposition, surface activity…

Diameter, change upon conditions

Factors influencing the size and diameter of particles over time: aggregation, dissociation, condensation, hygroscopy, evaporation



Case study

Stone cutting

Mr Red uses a mist blower to reduce his exposure to heat. He expects the quartz particles to coalesce with water droplets and to sediment quicker.
However, he observes that only solid particle does fall to the floor.

Question (3.1b)

Consider the relative speed of sedimentation of a particle (quartz) and a droplet of the same size.

What happened ?

Case-study solution

Question 3.1b

It is possible to calculate the falling speed of the two particles (correct theoretical answer). But, being a volatile product, the glycol ether droplet undergoes evaporation. This evaporation is very fast because of the large exchange surface (relative to its mass).
The application of Fick's law to a spherical droplet is written:

$$J(t)_j = 4 \cdot \Pi \cdot r(t) \cdot D_j \cdot M \cdot \frac{(P_{\mathrm{si}} - P_{\mathrm{ai}})}{R \cdot T}$$

With
T: 293 [°K]
P_s Saturation vapor pressure, P_{ai} vapor pressure in air
M: molecular weight

The (theoretical) order of magnitude of the initial evaporation of the droplet can be calculated by considering that the vapor pressure in the ambient air is zero.

$$J(t)_j = 7.9 \cdot 10^{-9} [g/s]$$

Now, the mass of the particle is

$$m_{\mathrm{goutellette}} = \rho_{\mathrm{LIQ}} \frac{4}{3} \pi r_0^3 = 1.3 \cdot 10^{-11} g$$

the liquid droplet **will evaporate completely before it hits the ground**.

Deposition mechanisms

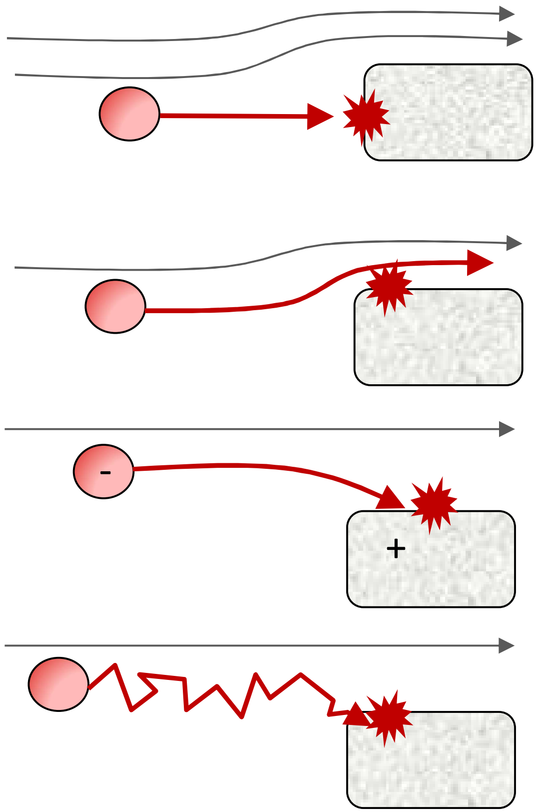
- **Sedimentation**
- **Impaction**

  - large particles are unable to follow the air stream
- **Interception**

  - contact with solid material
- **Electrostatic attraction**

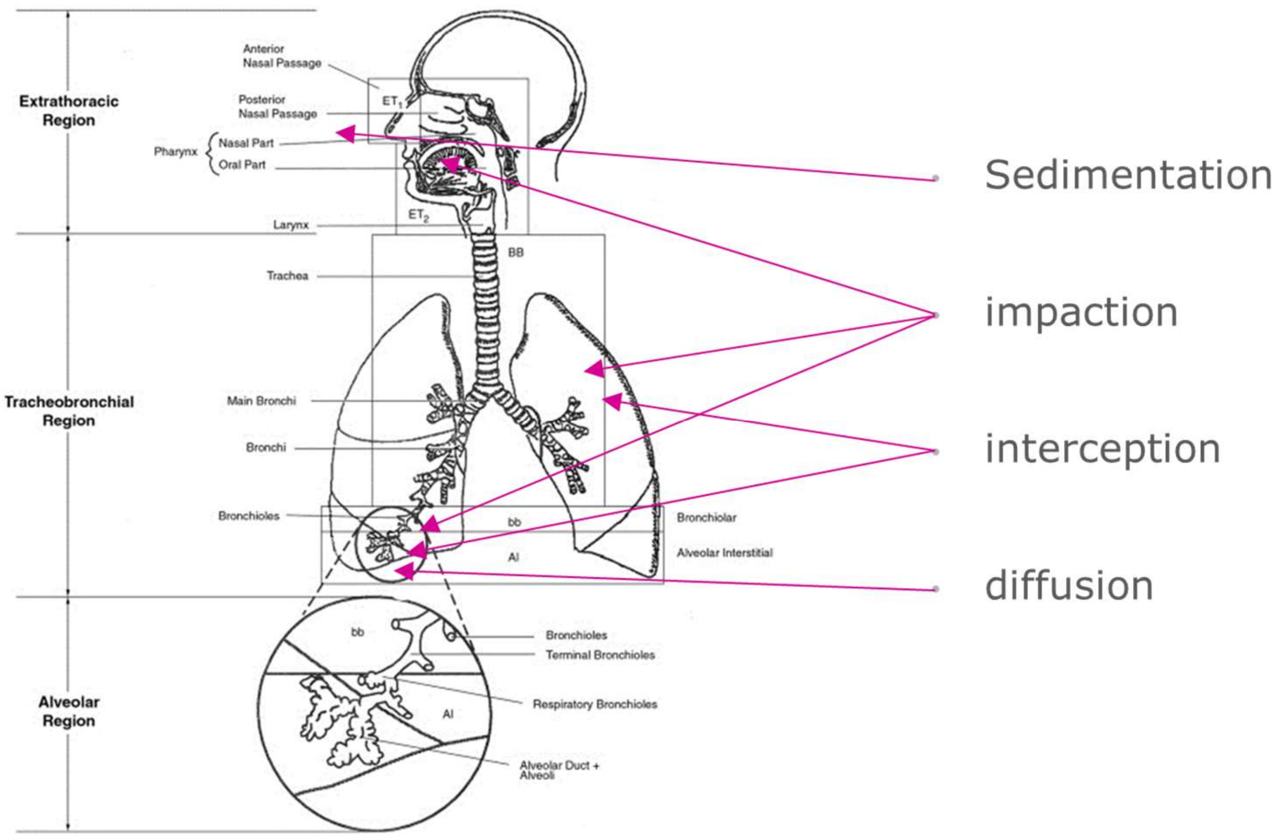
  - attraction from an electrically charged surface
- **Diffusion**: Brownian motion

  - Brownian motion



Lung deposition

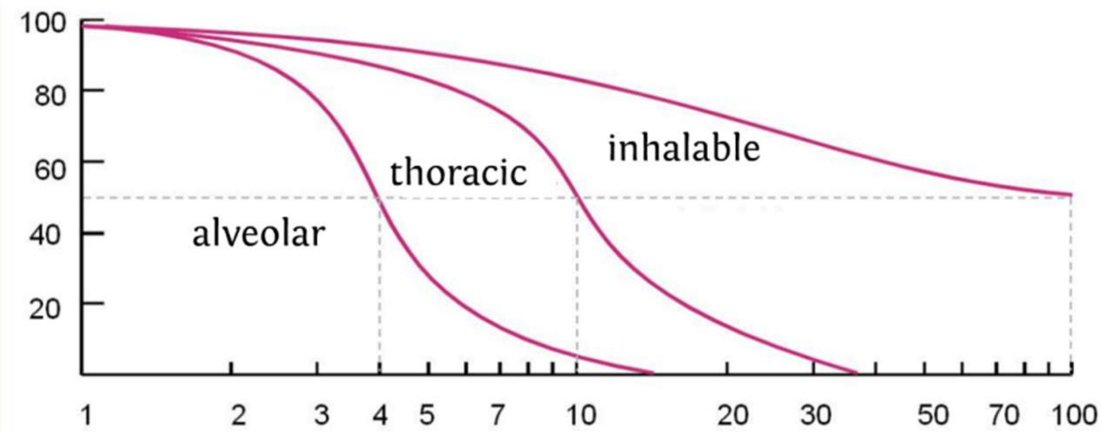
Deposition mechanisms



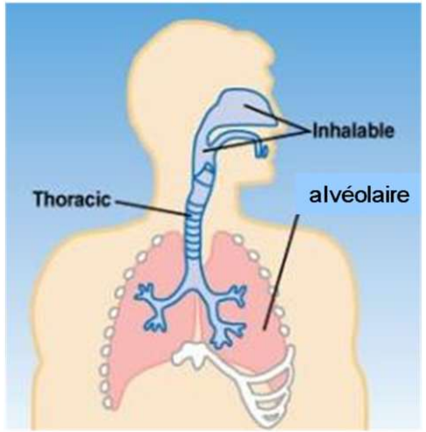
Lung deposition

Standardized deposition curves

- ISO-CEN standards
- Alveolar, thoracic and inhalable fraction (in % of total particles)

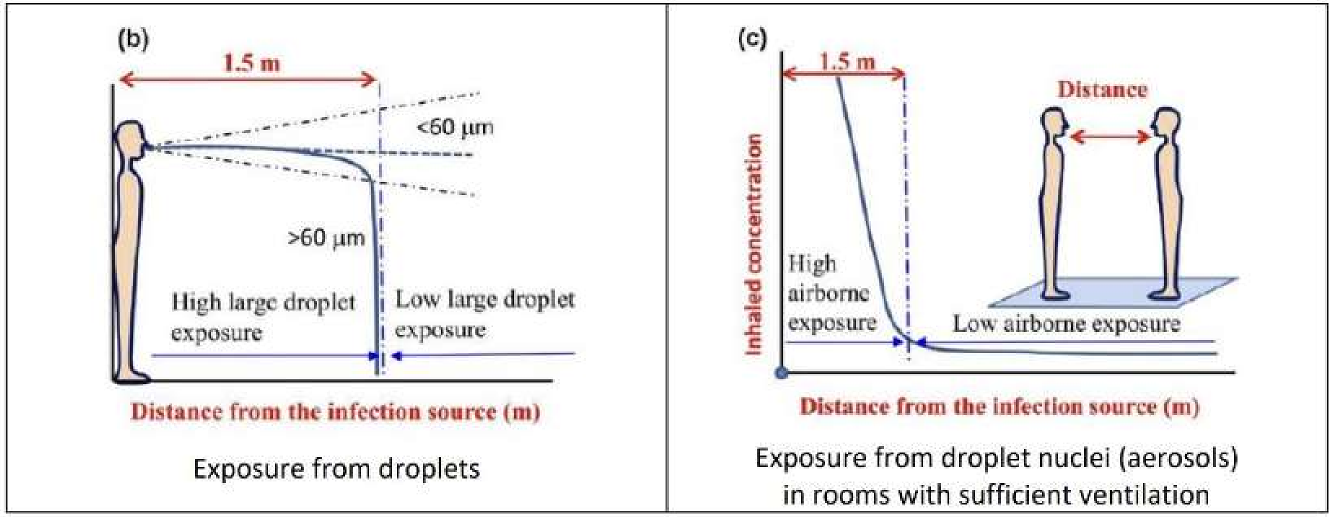


Aerodynamic diameter [μm]



Aerosol spreading (Covid-19)

Example, COVID 19



From Nielson 2020. Transmission by both aerosols and droplets is highest when close to the patient. Although aerosol transmission can occur at a distance, the vast majority will occur at close range.

Case study

Stone cutting

An aerosol measurement is taken at Mr Red workplace. The results show that a about 10% of particles are in the alveolar fraction and 60% in the inhalable fraction. The alveolar fraction increases when he uses powered tools.

Question (3.1c)

Explain why it is useful to measure particle size fractions in relation to their penetration into the respiratory system ?

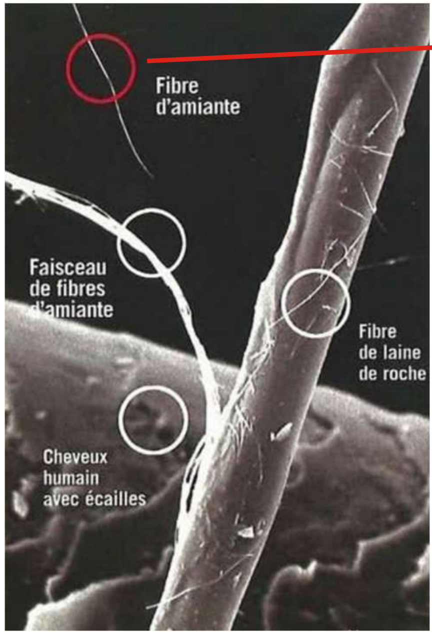
Case-study solution

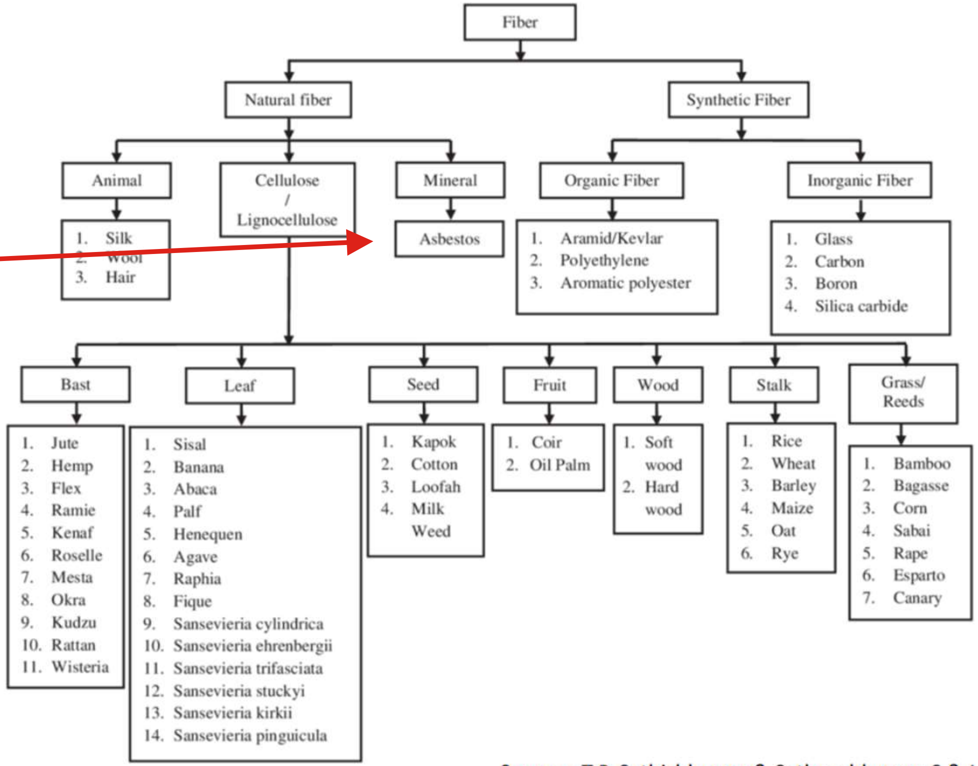
Question 3.1c

- The purpose of this air sampling is to evaluate risks for the health of exposed persons. In the case of dusts, it is thus a question of estimating the quantity ("dose") that will reach the target organ.
- For dusts containing systemic toxicants (reaching a "system" [target organ, immune system, reproductive system, hematopoietic system, etc.]), what matters most is the quantity that enters the body (inhalable fraction).
- For a dust acting on the bronchial tubes (e.g. flour), the thoracic fraction will be the most significant for the risk evaluation (in this case, of asthma caused by flour).
- For dusts acting deep in the lungs (alveoli), the alveolar fraction will be the one to be evaluated for risk assessment, since it is the one that will penetrate the area of interest. Quartz (silica) is an example.

Fibers

The fiber family





Source : T P, Sathishkumar & Satheeshkumar, S & J, Naveen. (2014). Hybrid fiber reinforced polymer composites - A review. Journal of Reinforced Plastics and Composites. 33. 454–471.

Definitions (fibers)

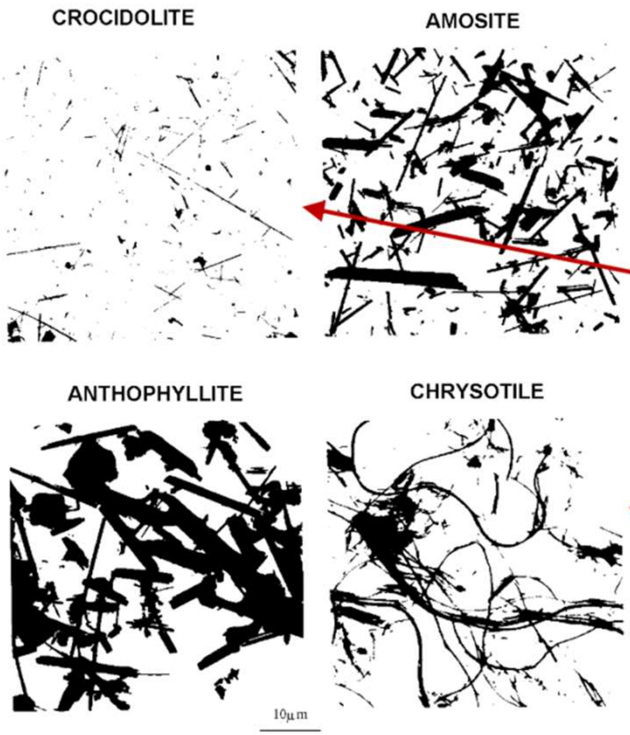
WHO definitions

- Analogy with asbestos fibers (convention)
- Are to be considered as biologically significant, particles whose:
  - Length/diameter ratio exceeds 3:1
  - Length exceeds 5 µm
  - Diameter is less than 3 µm

- Exemple of asbestos
  - Analysis through phase contrast microscopy
  - Particles that does not meet this criteria are not considered fibers
  - Short asbestos fibers < 5 µm
  - Fine fibers < 0.2 µm

Fibers

The asbetos family



Appearance of asbestos fibers under the optical microscope

Blue asbestos

White asbestos

Asbestos

Some history about asbestos

- Historical use in construction
- Mainly during the 50s and 70s
- Diseases in asbestos workers known since the beginning of the (past) century

- intense lobbying by the fiber industry
- general ban in Switzerland in 1989
- 100'000 deaths per year according to the WHO
- In 2015, the reopening of the Jeffrey mine (closed in 2010) was still being discussed

Jeffrey asbestos mine in Asbestos (Canada)

Asbestos

Where is there any left ?

In the materials

- More production/importation
- Public and private buildings
  - *insulation, plastering, mastics, false ceilings...*
- In technical/industrial facilities
  - *ovens, heating systems, vehicles*
- In the waste

Natural sources

- Rocks, underground deposits
- Surface outcrop (e.g. Corsica, New Caledonia)

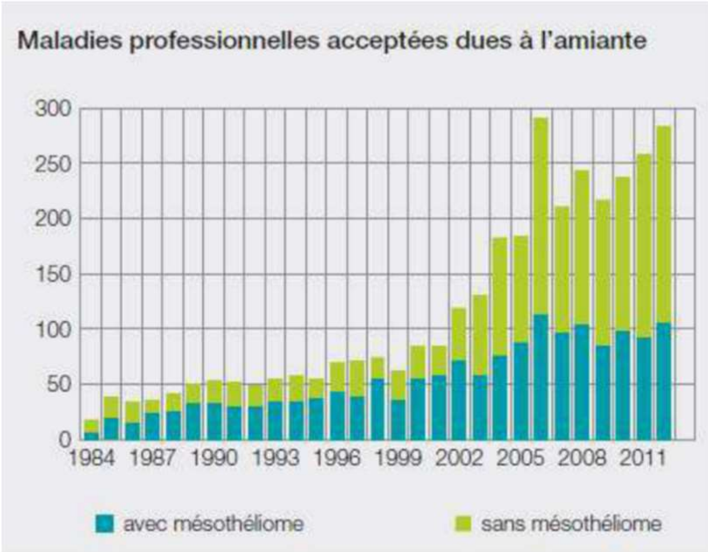
A professional nuisance, really?

Les Cahiers d'Outre-Mer, Number 252

Asbestos

Related pathologies

- Non malignant
    - Asbestosis
    - Pleural plaques
    - Pleural thickening…
- Malignant
    - Mesothelioma
    - Lung cancer
    - Ovarian cancer
    - Laryngeal cancer
- Other unclear associations
    - Kidney, bladder…



Asbestos

Mesothelioma

- Very slow development (onset 20-40 yrs after exposure)
- We are currently in the peak period

Evolution of asbestos exposure and expected mesothelioma in Switzerland