Atmospheric Aerosols

Lecture 4

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Aerosol Particle Size: Diameter vs. Effective Diameters

Molecules and nano- particles are not spheres and have no distinct geometric surface.

For many particles, spherical geometry good assumption.
"Diameter" has physical meaning

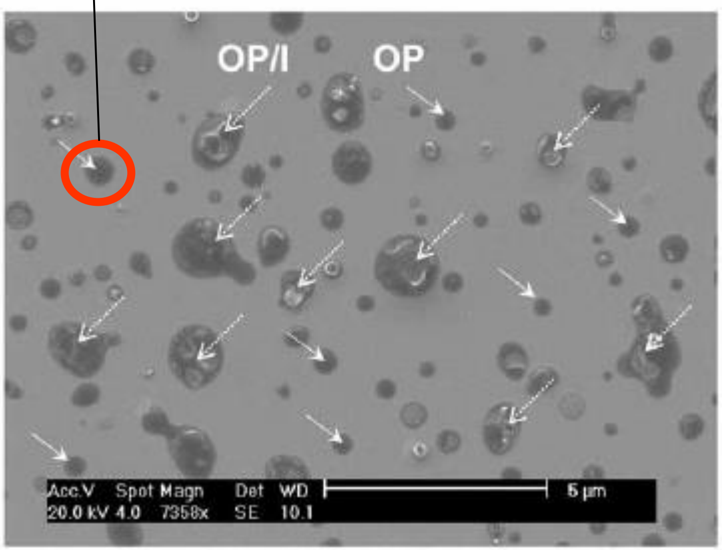


Figure 2. Organic particles with (OP/I) and without inclusions (OP) (sample DOY 228.73). Particles with no inclusions are shown with solid arrows, and particles with inclusions are shown with dashed arrows.

Spherical?

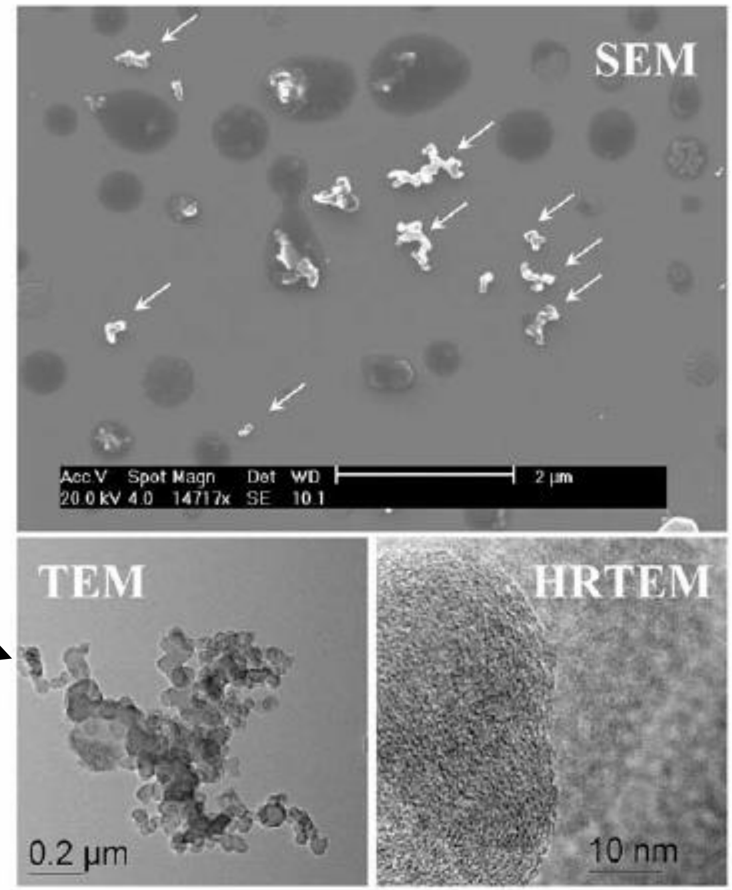
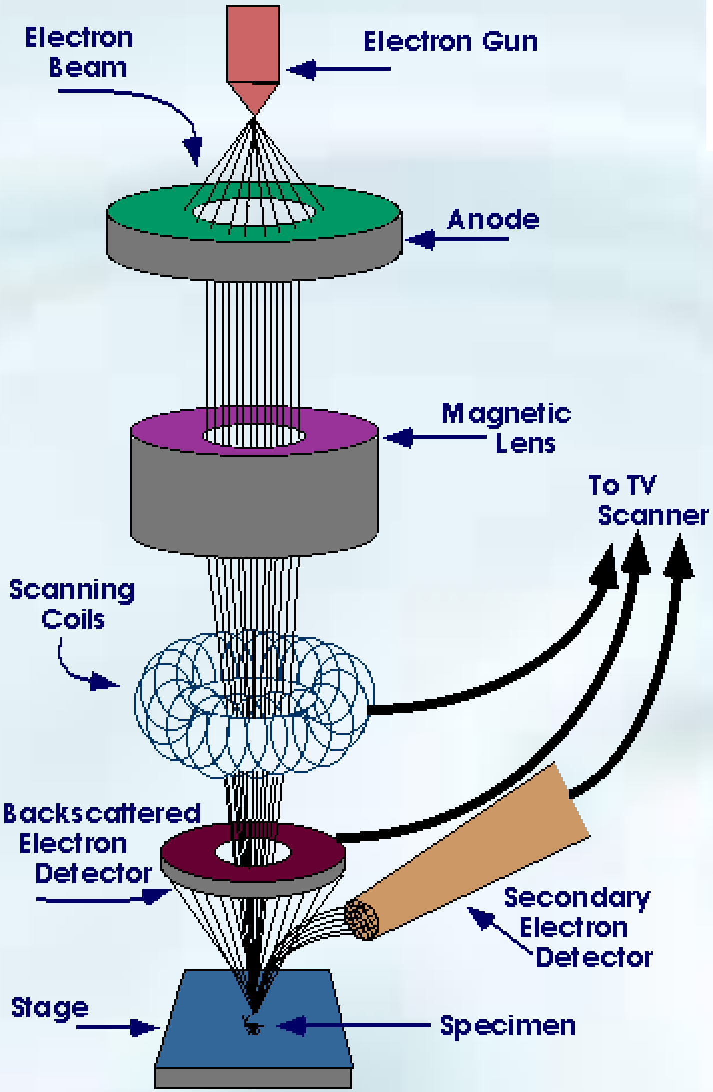


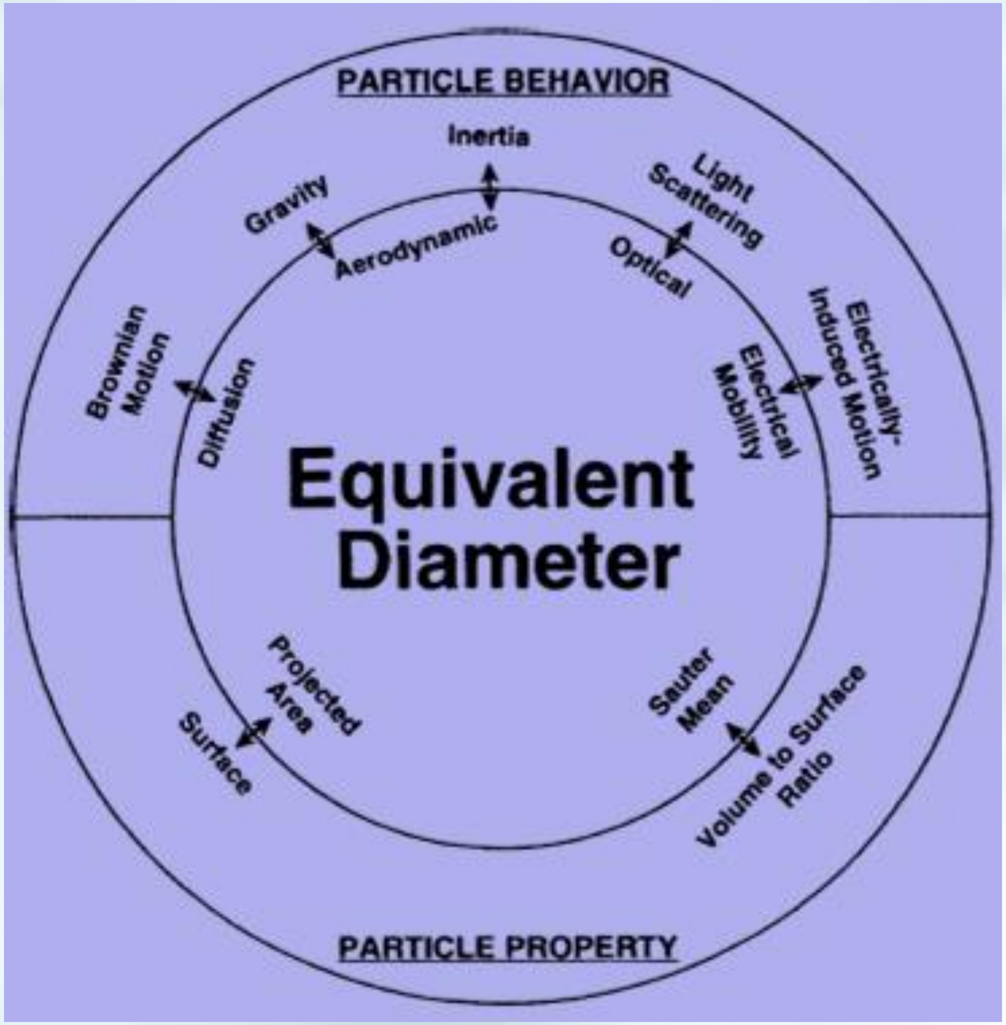
Figure 6. Typical soot particles from SEM, TEM and HRTEM images (sample DOY 228.729). Arrows point to soot particles.

scanning electron microscope



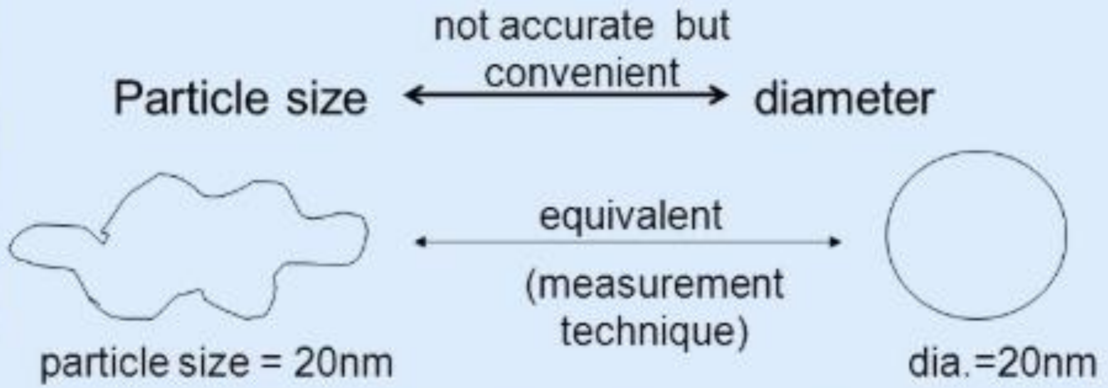
Equivalent Diameters

Particle size definitions that depend on observations of particle properties or behavior.



F. Particle size:

Particle size means usually a certain kind of equivalent diameter of a particle.



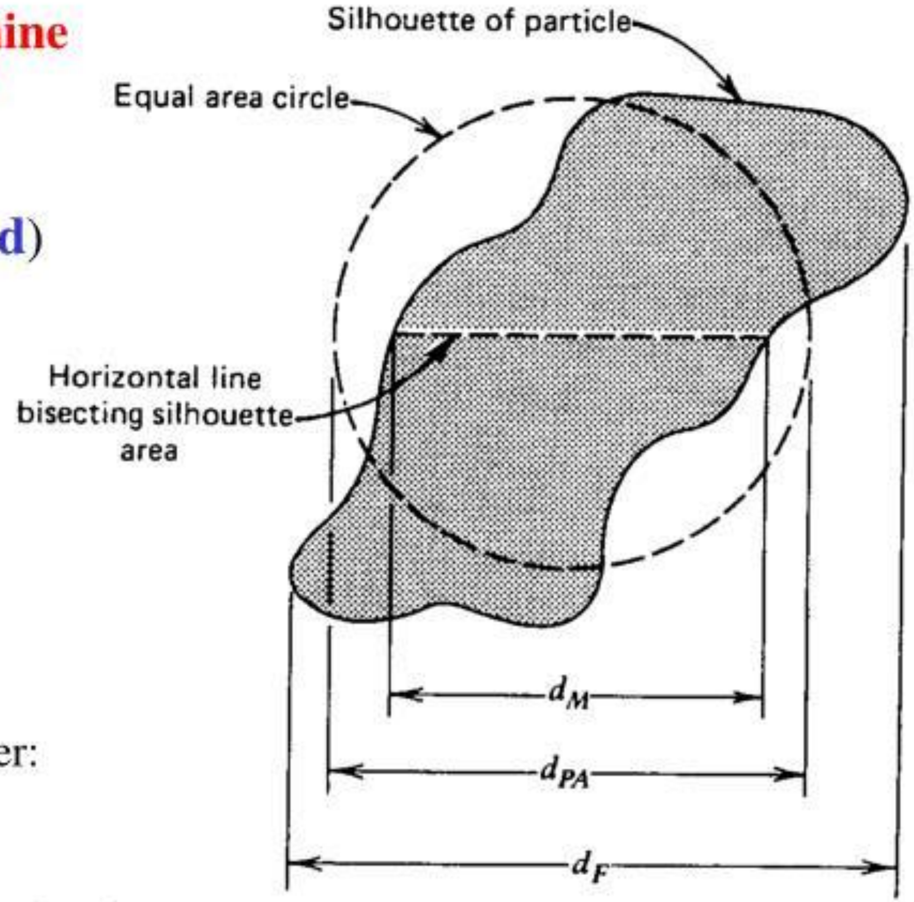
- It has a definite value only when the particles are spherical in shape.
- For non-spherical particles, their diameter depends on specific definition or practically on the measurement technique. (e.g., mass equivalent diameter, volume equivalent diameter.)

Microscopic Measurement of Particle Size

Reading: Chap 20

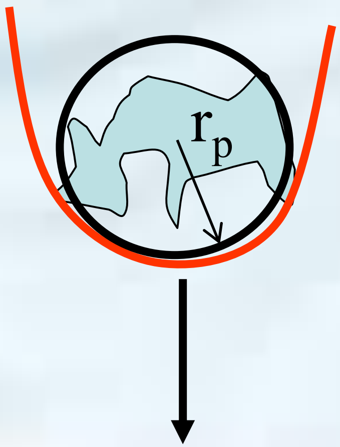
Q: How do you determine this particle's size?

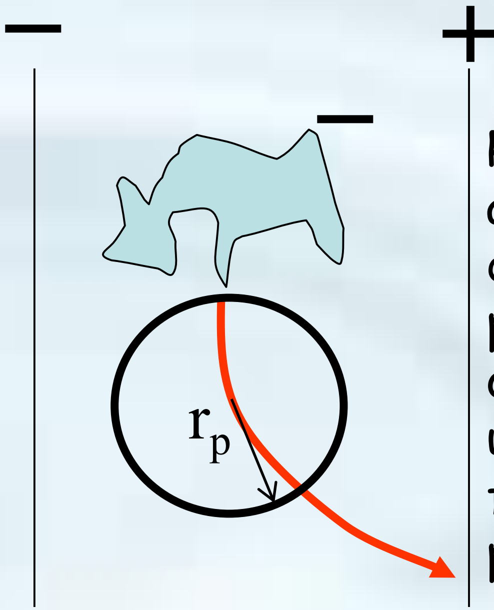
- Equivalent sizes of Irregular Particles (**2-d**)
  - Martin's diameter:
  - Feret's diameter:
  - Projected area diameter:



Q: Orientation?

Some Effective or Equivalent Diameters





Relation to aerodynamic diameter and other physical properties of particle not well understood for fractal like soot particles.

Aerodynamic Diameter

Same terminal falling speed in air as a particle with density 1g/cm^3 and radius r_p

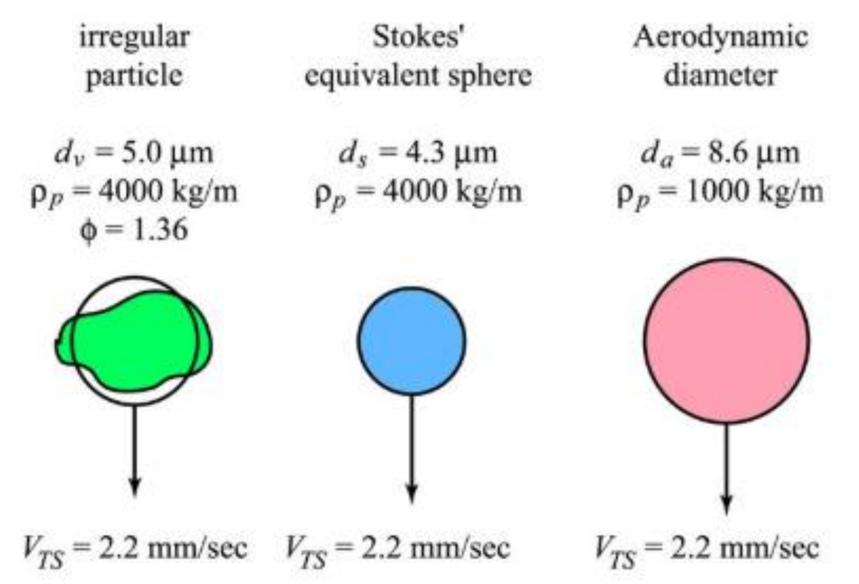
Electric Mobility Diameter

Same trajectory in calibrated electric field as a spherical singly charged particle with radius r_p

Aerodynamic Diameter

Consider an aerosol particle

Its Aerodynamic Diameter is the diameter of a water droplet that falls at the same speed as the aerosol particle



Comparison of equivalent volume diameter, Stokes diam

Water
1 gm / cm^3

Size Number Distribution

Particles, like gases, are characterized by chemical content, usually expressed in μgm^{-3}, but unlike gases, particles also have a characteristic size. We may want to start discussion the characteristics of atmospheric aerosols by addressing the question "What is the mean diameter of the particles?" The answer to this question changes with your point of view.

If your concern is the mass of some pollutant that is being transported through the air for biogeochemical cycles, then you want to know the mean diameter of the particles with the mass or volume. In other words, "What size particles carry the most mass?"

If your concern loss of visibility then you want to know the diameter of the particles that have the largest cross section or surface area. In other words, "What size particles cover the largest surface area?"

If your concern is cloud formation or microphysics then you want to know the range of diameters with the largest number of particles. In other words, "What is the size of the most abundant particles?"

If your concern is human health then you need to know about both the mass and number of the particles, because only a certain size particle can enter the lungs.

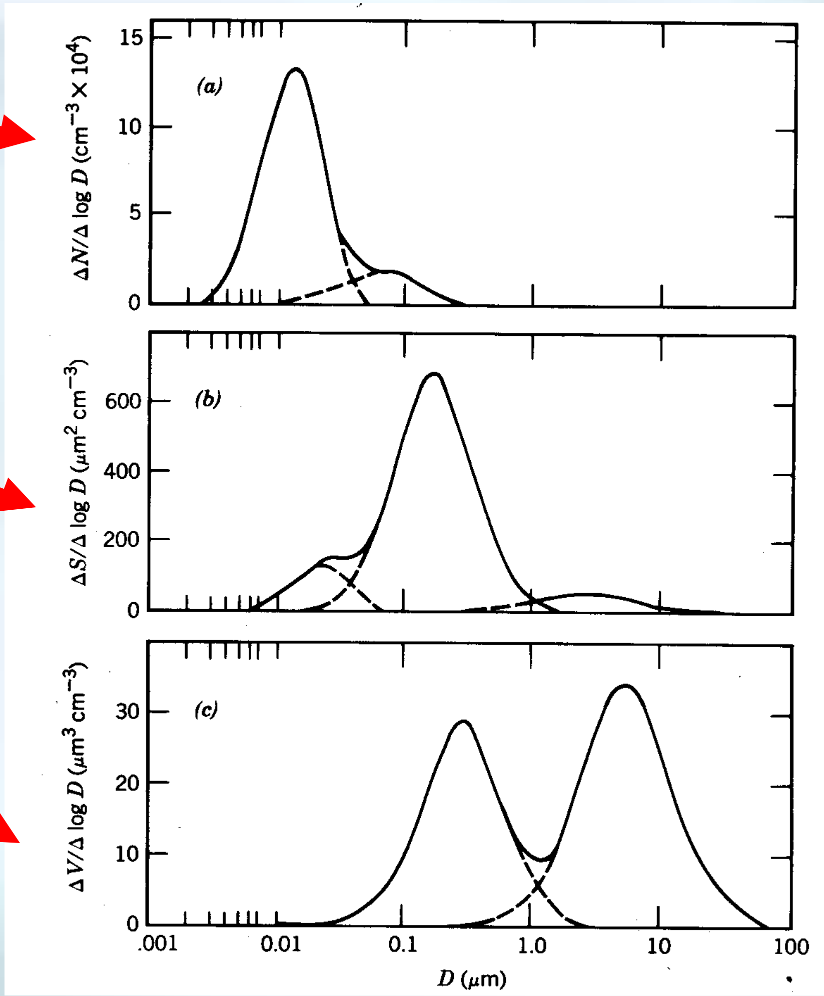
Aerosol Distributions

Number
cloud formation

Surface
visibility

Volume
mass

Mass & Number
human health



Particle size distribution of atmospheric aerosols

The diameters of atmospheric aerosol particles span over four orders of magnitude, from a few nanometers to around 100 μm.

Particle number concentrations may be as high as 10^7 to 10^8 cm^{-3}.

Thus, a complete description of the aerosol size distribution may be a challenging problem.

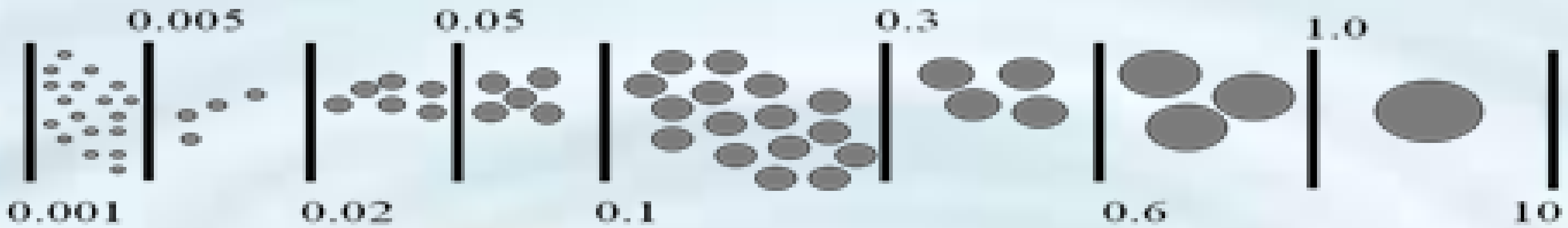
Therefore, several mathematical approaches are used to characterize the aerosol size distribution.

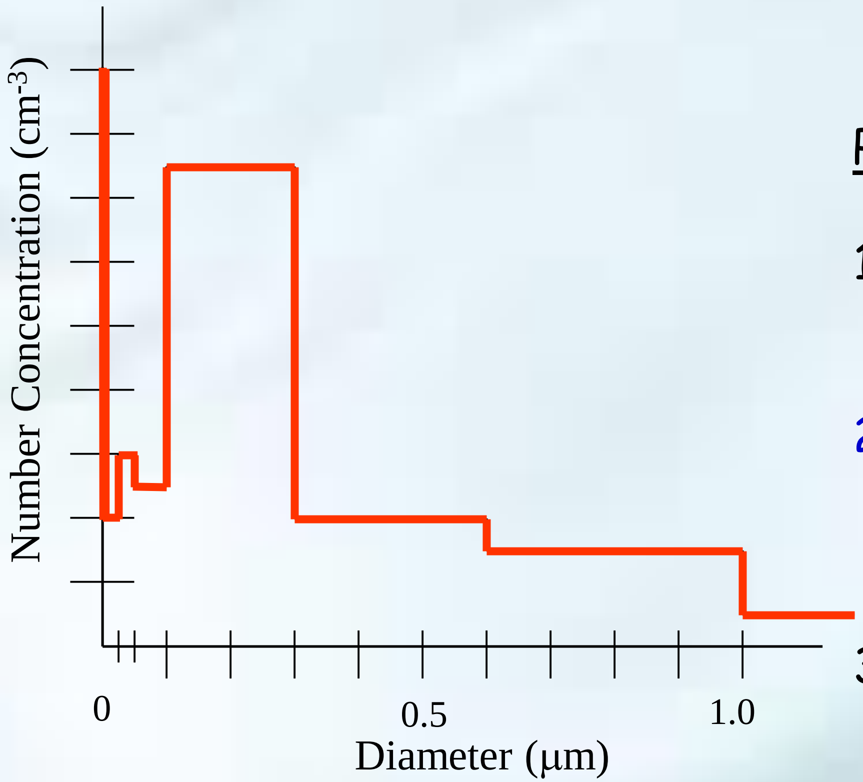
Discrete approximation: particle size range is divided into discrete intervals (or size bins) and the number of particles is calculated in each size bin.

Continuous approximation: particle size distribution is represented by analytical function vs. radius.

Let's consider first discrete approximation of aerosol size distribution.

Bean Counting: Aerosol Size Distributions





Problems

1. Information lost at small sizes due to large size range

2. Comparing particle concentrations in different bins marred by varying bin size

3. Area under curve is not proportional to total particle number concentration

Table 25.2. Example of segregated aerosol size information.

Size range (μm)	Concentration (cm^{-3})	Cumulative concentration (cm^{-3})	Normalized concentration ($\mu m^{-1} cm^{-3}$)
0.001 - 0.01	100	100	11111
0.01-0.02	200	300	20000
0.02-0.03	30	330	3000
0.03-0.04	20	350	2000
0.04-0.08	40	390	1000
0.08-0.16	60	450	750
0.16-0.32	200	650	1250
0.32-0.64	180	830	563
0.64-1.25	60	890	98
1.25-2.5	20	910	16
2.5-5.0	5	915	2
5.0-10.0	1	916	0.2

Cumulative concentration is defined as the concentration of particles that are smaller than or equal to a given size range.

Normalized concentration is defined as the concentration of particles in a size bin divided by the width of this bin.

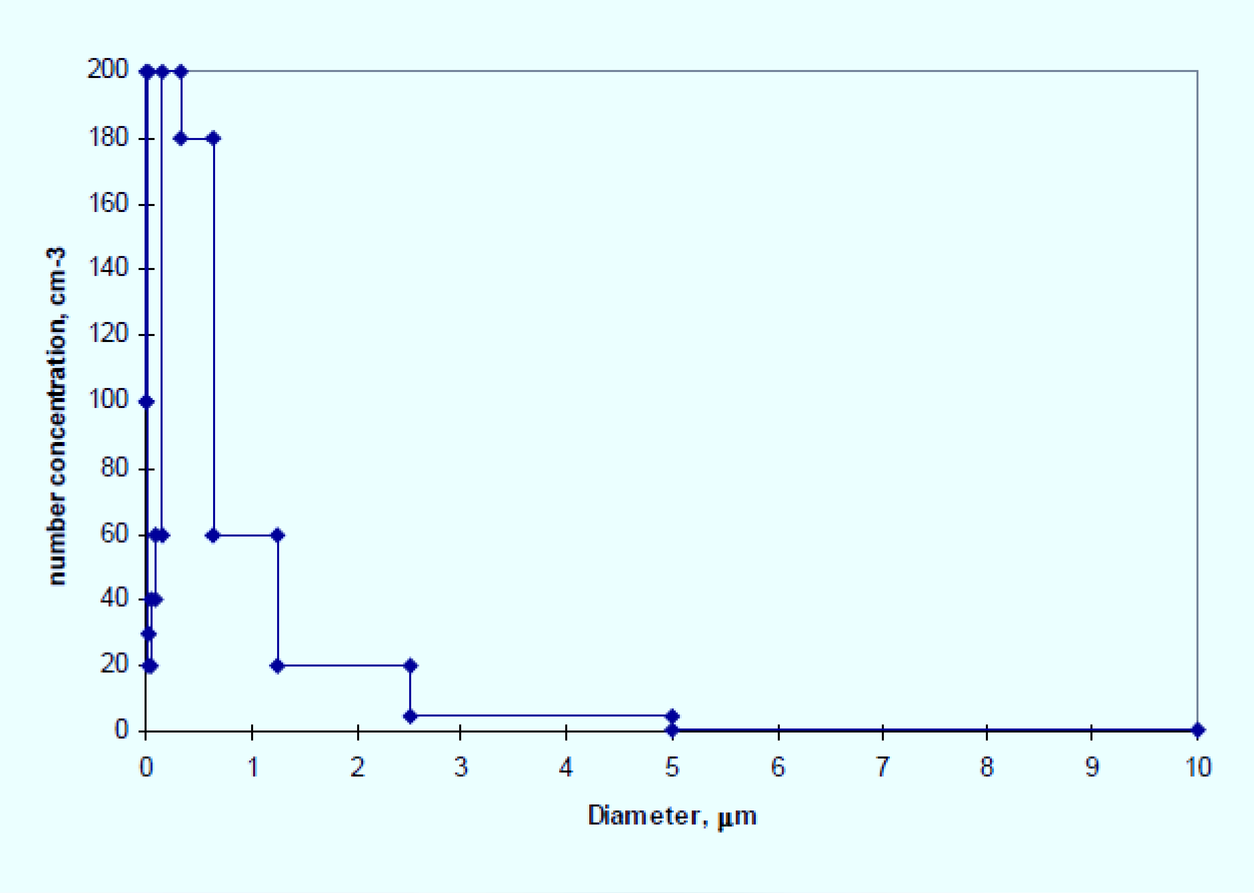
If the i-bin has Ni particle concentration, thus normalized concentration in the i-bin is:

$$nNi = Ni / \Delta Di$$

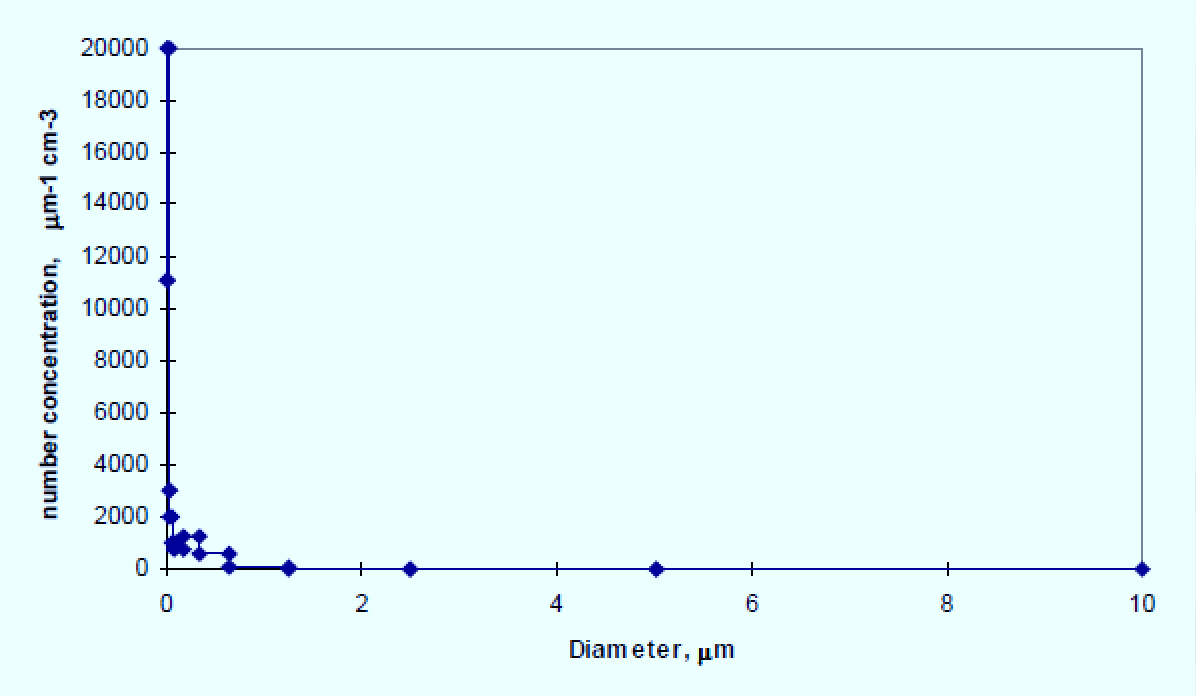
where ΔDi is the width of the i-bin.

Discrete size distribution is typically presented in the form of histogram.

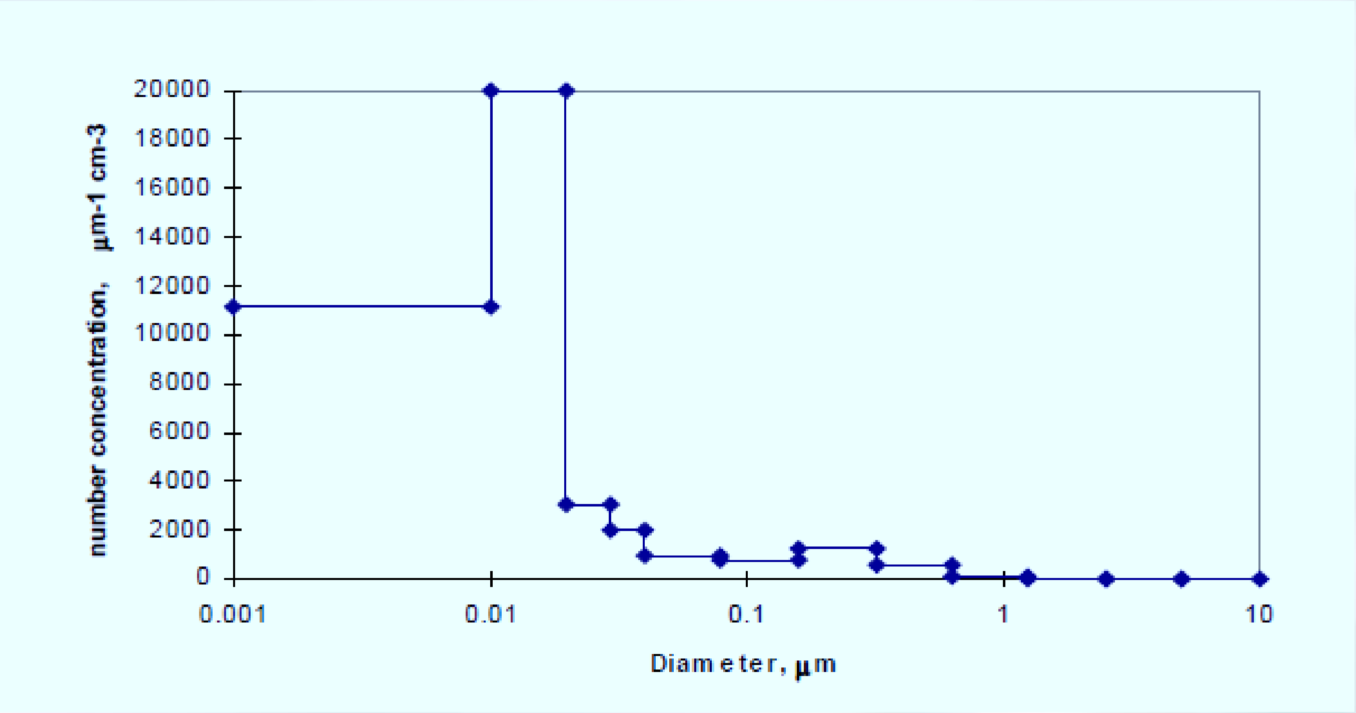
Figure, Histogram of aerosol particle number concentrations vs. the size range for the distribution of Table.



Histogram of aerosol particle number concentration normalized by the width of the size range for the distribution of Table



Same as previous Figure but plotted vs. the logarithm of the diameter.



NOTE: That in Figures 1 & 2 smaller particles are hardly seen, but if a logarithmic scale is used for the diameter (Figure 3) both the large- and small-particles regions are depicted.

Major limitation of discrete approximation:

loss of information about the distribution structure inside each bin. Let's consider **continuous approximation**.

We can define the size distribution function $n_N(D)$ as follows:

$$n_N(D)\, dD \qquad \text{(particles cm}^{-3}/\mu\text{m)}$$

$n_N(D)\, dD$ = the number of particles per cm^3 of air having diameters in the range D and D+dD (here dD is an infinitesimally small increase in diameter).

If units of $n_N(D)$ are $\mu m^{-1} cm^{-3}$ and

the total number of particles per cm^{-3} , N, is then just

$$N = \int_{0}^{\infty} n_N(D)\, dD \qquad \text{(particles/cm}^3\text{)}$$

On the other hand $n_N(D) = dN / dD$

NOTE: both sides of the equation above represent the same aerosol distribution, and both notations are widely used.

Several aerosol properties depend on the particle surface area and volume distributions with respect to particle size.

We can define a surface area distribution function, $n_s(D)$, for spherical particles as follows:

$$n_s(D)dD = \pi D^2 \, n_N(D) \qquad (\mu m^2\ \mu m^{-1}\ cm^{-3})$$

$n_S(D)\,dD$ = the surface area of particles per cm^3 of air having diameters in the range D and D+dD (here dD is an infinitesimally small increase in diameter).

If all particles are spherical and have the same diameter D in this infinitesimally narrow size range that each of them has surface area πD^2, we have

Here $n_S(D)$ is in μm cm^{-3}

Thus the total surface area S of the aerosol particles per cm^3 of air is given by the integral over all diameters

$$S = \int^{\infty} n_s(D)\,\mathrm{dD} = \pi \int^{\infty} D^2 n_N(D)\,\mathrm{dD} \qquad (\mu\mathrm{m}^2\mathrm{cm}^{-3})$$

Let's define aerosol volume distribution $n_V(D)$ as

$n_V(D)\ dD$ = the volume of particles per cm^3 of air having diameters in the range D and D+dD (here dD is an infinitesimally small increase in diameter),

and therefore

$$n_v\,(D_p)\ dD = \{\pi/6\}\ D^3\ n_N\,(D) \qquad (\mu m^3\ \mu m^{-1}\ cm^{-3})$$

Here $n_V(D)$ is in $\mu m^2\ cm^{-3}$.

Thus the total aerosol volume **V** per cm^3 of air is

$$V = \int^{\infty} n_v(D)\ dD = \pi/6 \int^{\infty} D^3 n_N(D) dD \qquad (\mu m^3 cm^{-3})$$

Here V is in $\mu m^3\ cm^{-3}$