Atmospheric Pollution

Lecture 7

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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

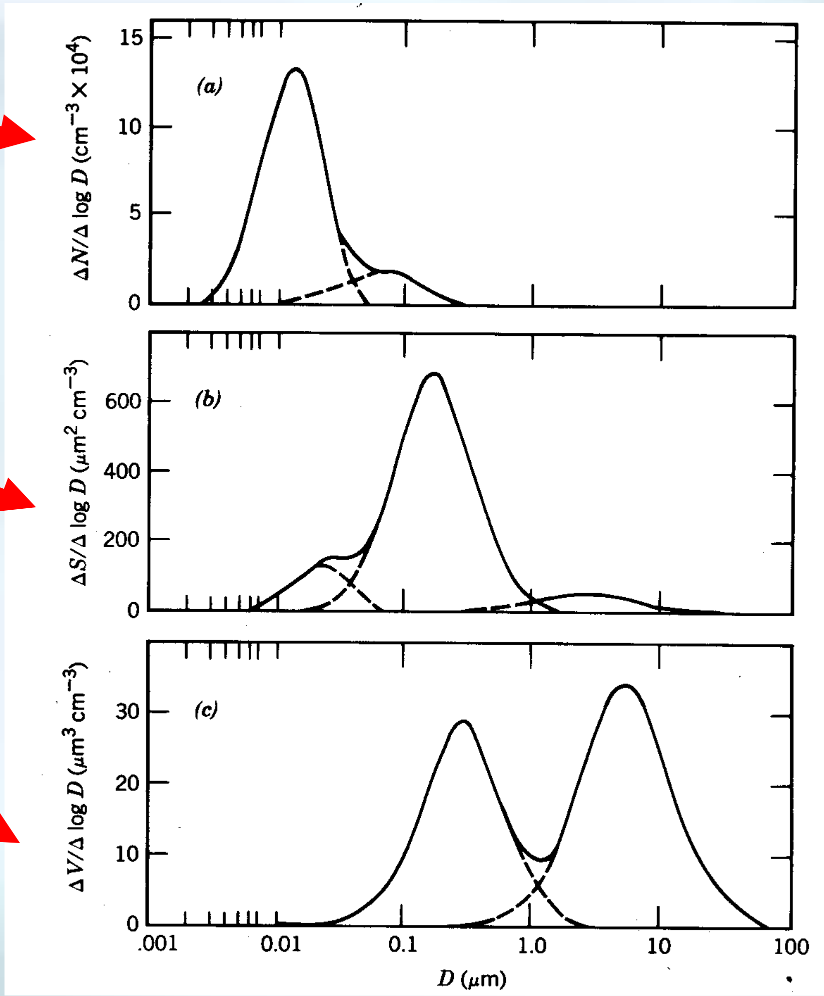
visibility

Volume

mass

Mass & Number

human health



Aerosol Particle Size: Diameter vs. Effective Diameters

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

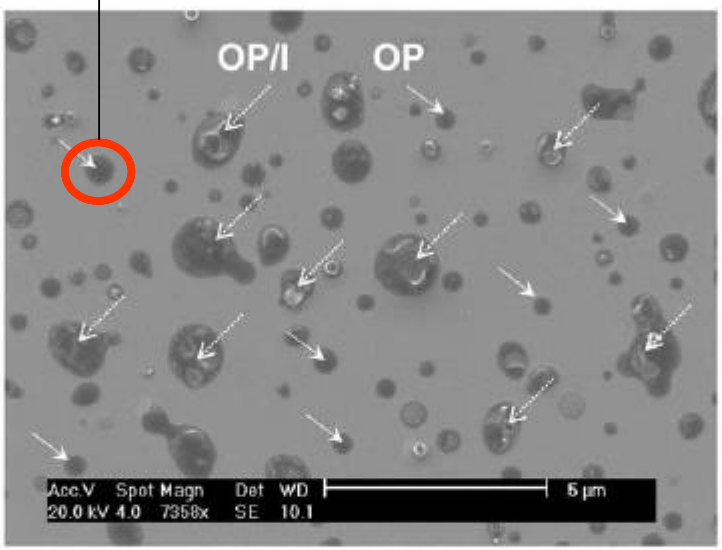


Figure 2. Organic particles with (OP/I) and without inclusions (OP) (sample DOY 228.73). Particles with no inclusions are shown with solid arrows, and particles with inclusions are shown with dashed arrows.

Spherical?

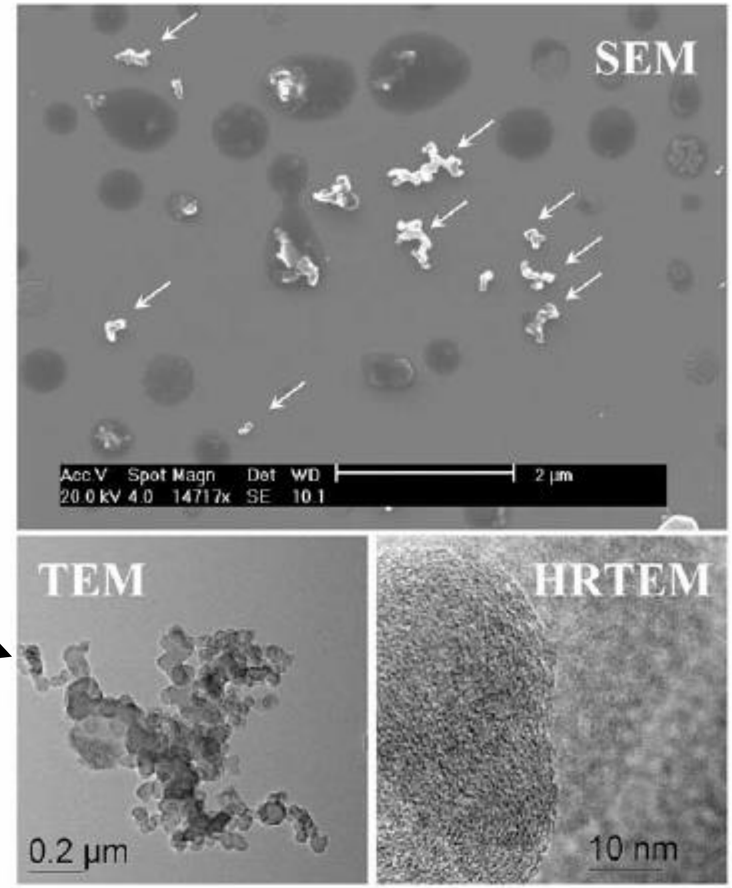
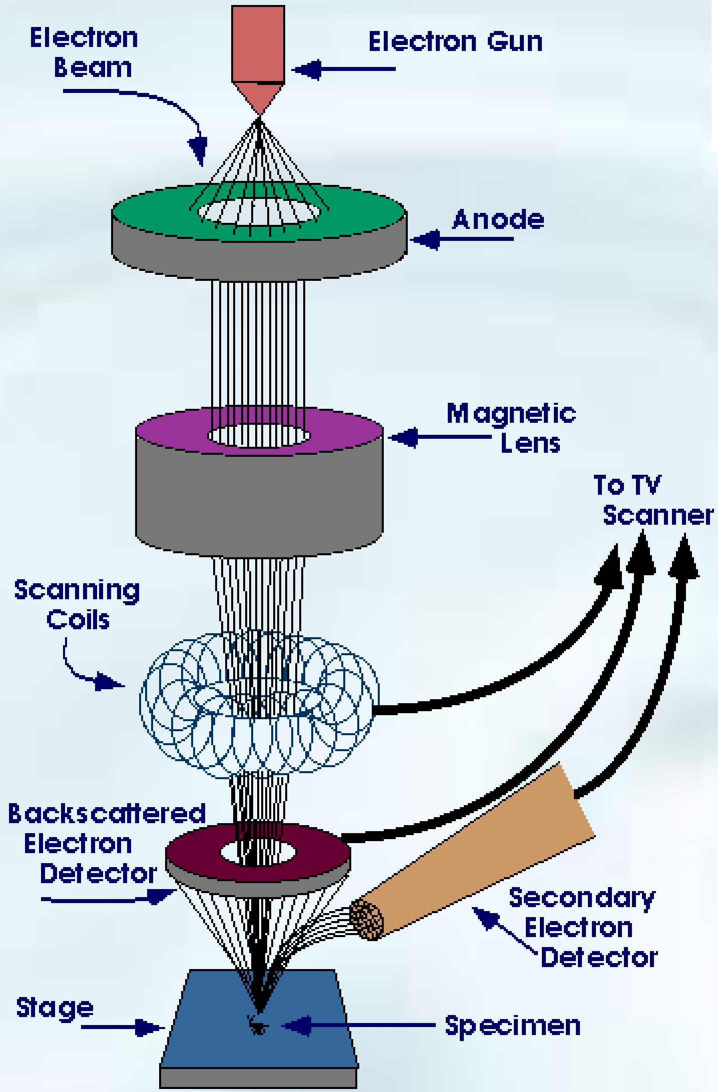
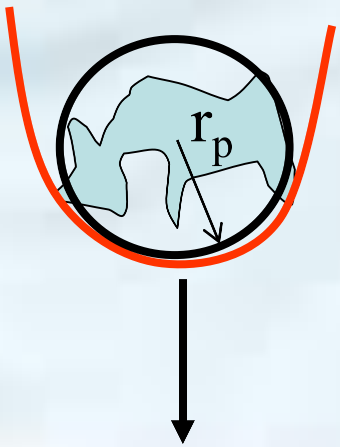


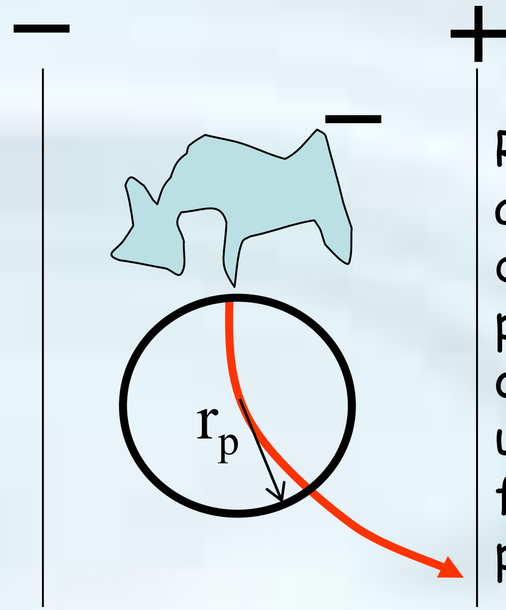
Figure 6. Typical soot particles from SEM, TEM and HRTEM images (sample DOY 228.729). Arrows point to soot particles.


SEM


Electron Beam
Electron Gun
Anode
Magnetic Lens
To TV Scanner
Scanning Coils
Backscattered Electron Detector
Secondary Electron Detector
Stage
Specimen

Some Effective 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 $1 g/cm^3$ 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

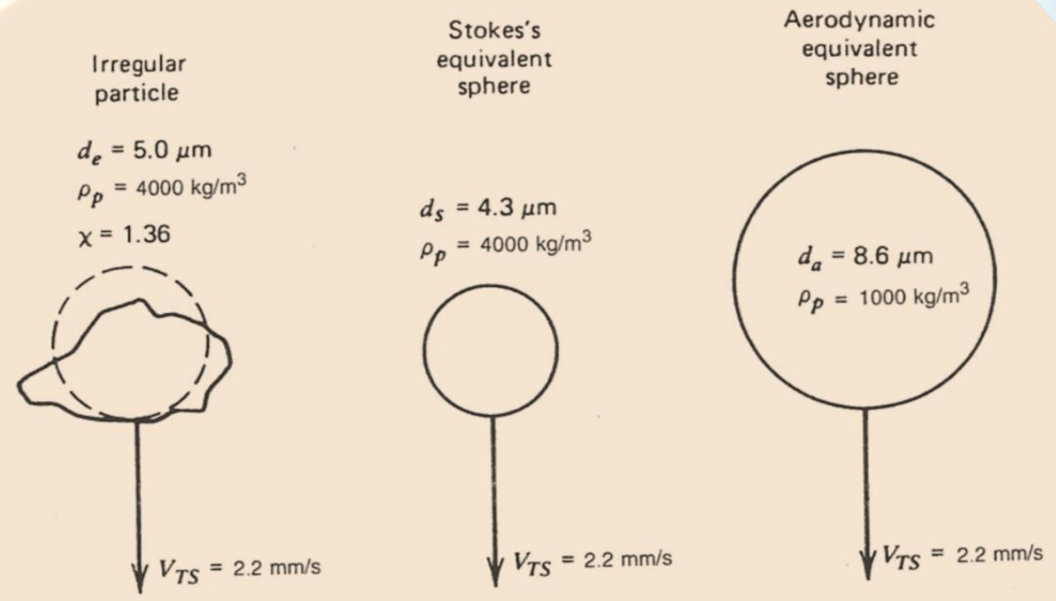
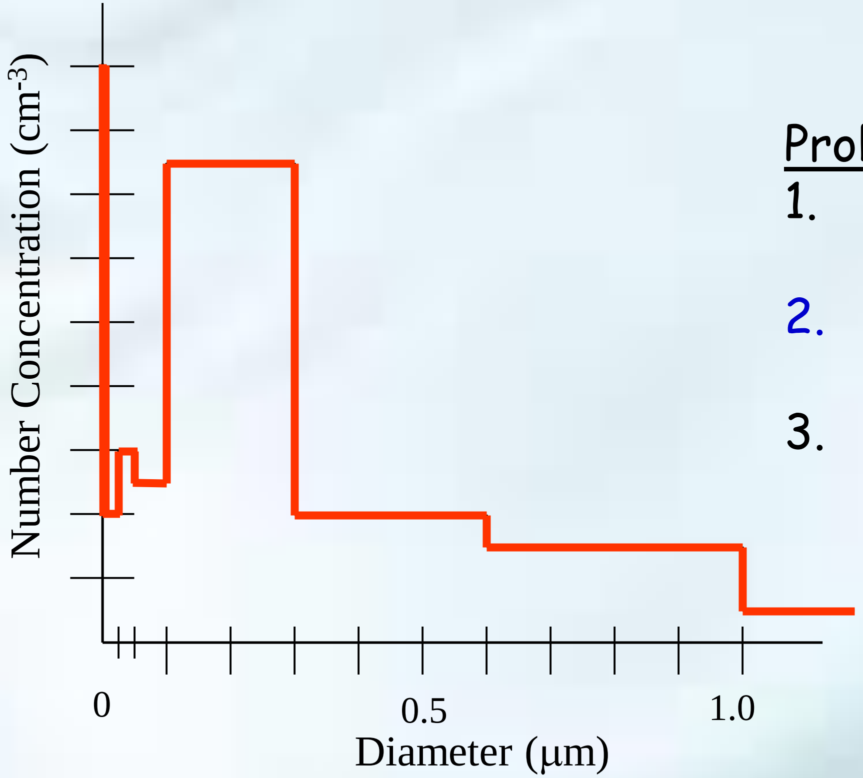


FIGURE 3.3 An irregular particle and its equivalent spheres.

Water
1 gm / cm^3

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

the number distribution function, $f_n(D_p)$,

the number of particles with diameter between D_p and $D_p + dD_p$ in a cm^3 of air as follows:

$$f_n(D_p)\, dD_p \qquad (\text{particles } cm^{-3}/\mu m)$$

The total number of particles, N,

is given by the following integral (everywhere we integrate from 0 to infinite diameters):

$$N = \int^{\infty} f_n(D_p)\, \mathrm{dD}_p \qquad (\text{particles}/\text{cm}^3)$$

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

$$f_s(D_p)dD_p = \pi D_p^2 f_n(D_p) \qquad (\mu m^2\ \mu m^{-1}\ cm^{-3})$$

This gives the surface area of particles in a size range per cm^3 of air.

The total surface area of the particles, S, is given by the integral over all diameters:

$$S = \int_{\cdot}^{\infty} f_s(D_p)\, \mathrm{d}D_p = \pi \int_{\cdot}^{\infty} D_p^2 f_n(D_p) \mathrm{d}D_p \qquad (\mu m^2 cm^{-3})$$

Likewise the volume distribution function and the total volume:

$$f_v\,(D_p)\,dD_p = \{\pi/6\}\,D_p^{\,3}\,f_n\,(D_p) \qquad (\mu m^3\,\mu m^{-1}\,cm^{-3})$$

$$V = \int^{\infty} f_v(D_p)\,\mathrm{dD}_p = \pi/6\int^{\infty} D_p^3\,f_n(D_p)\mathrm{dD}_p \qquad (\mu m^3 cm^{-3})$$

The distributions based on log D_p can be defined in a similar manner, where

$n(\log D_p) d\log D_p$ is the number of particles in one cm^3 with diameter

from D_p to D_p + log D_p. The total number is:

$$N = \int^{\infty} n(\log D_p)\,\mathrm{d(logD}_p) \qquad (\text{particles/cm}^3)$$

The normalized distribution functions based on log D_p for surface area and volume are similar. For the differential number of particles between D_p and $D_p + dD_p$ we use the notation dN, and likewise dS and dV, we can represent the size distribution functions as -

$$n(\log D_p) = \{dN\} / \{N \, d\log D_p\}$$

$$n_s(\log D_p) = \{dS\} / \{S \, d\log D_p\}$$

$$n_v(\log D_p) = \{dV\} / \{V \, d\log D_p\}$$

This is the common notation for expressing the variation in particle number, surface area or volume with the log of the diameter.

Log-normal distributions

Number distribution →
$n_n(\log D_p) = dN/d \log D_p$

Surface area distribution →
$n_s(\log D_p) = dS/d \log D_p$

Volume distribution →
$n_v(\log D_p) = dV/d \log D_p$

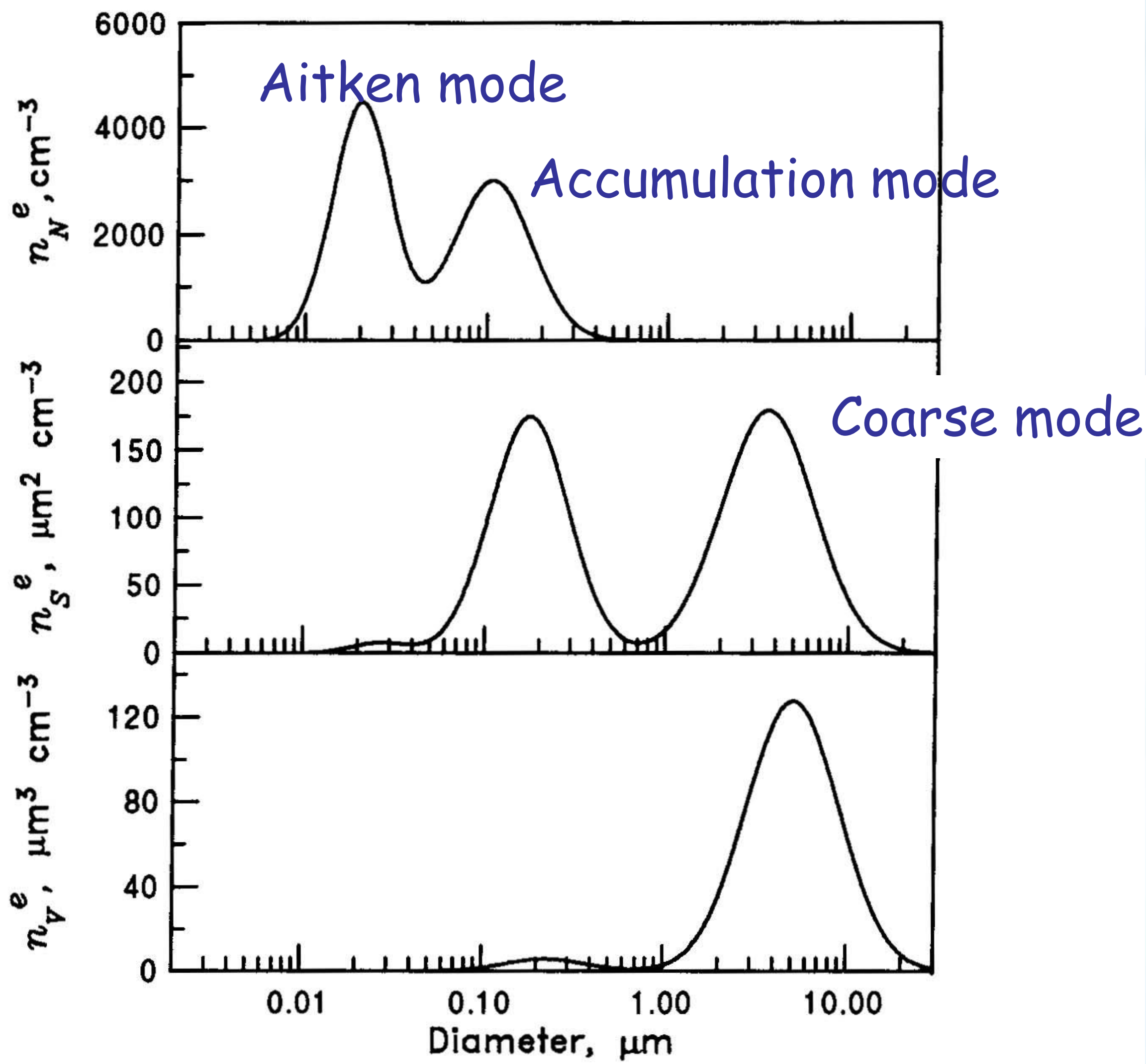


FIGURE 7.6 The same aerosol distribution as in Figures 7.4 and 7.5 expressed as a function of log D_p and plotted versus log D_p. Also shown are the surface and volume distributions. The areas below the three curves correspond to the total aerosol number, surface, and volume, respectively.

Aerosols measurement and instruments

Parameter	Instrument	**Holme Moss Site** HM1 HM2 HM3	Time Resolution
Particle Size distribution $dN/dlogD_p$	DMPS (3-800 nm) DMPS (20-400 nm) ASASP-X (100-3000 nm)	**x x** **x** **x** **x** **x** **x**	10 min 1 min
Size resolved hygroscopicity	TDMA	**x**	1 hour
Aerosol volume absorption coefficient	PSAP	**x**	
Berner Impactor	6 –Stage (organics + mass) 6 – Stage (Inorganic) 8 –Stage (mass + chemical analysis)	**x** **x** **x** **x**	3 hours 3 hours 3 hours

Cascade Impactor

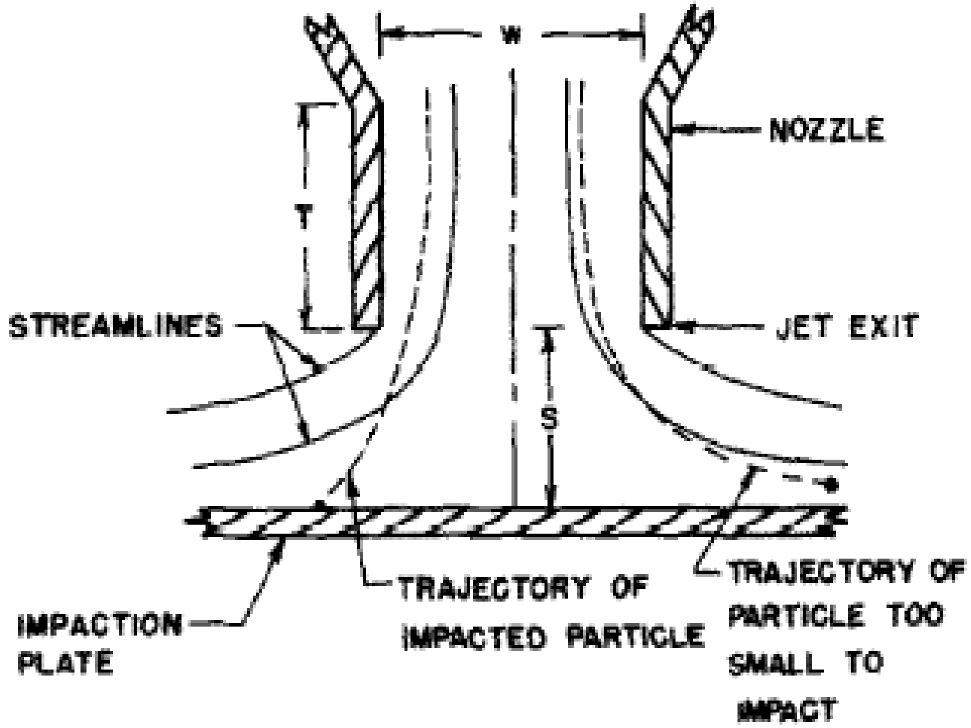
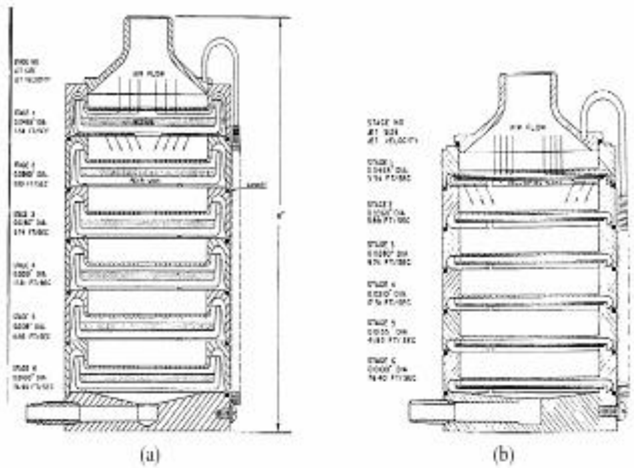


Fig. 1. Streamlines and particle trajectories for a typical impactor.



Cascade Impactor

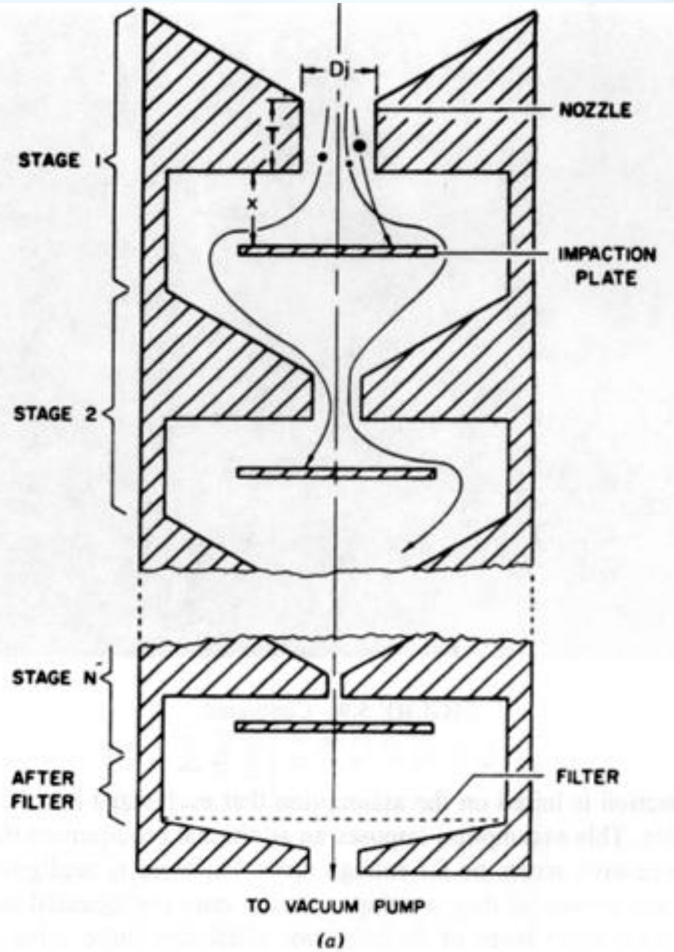
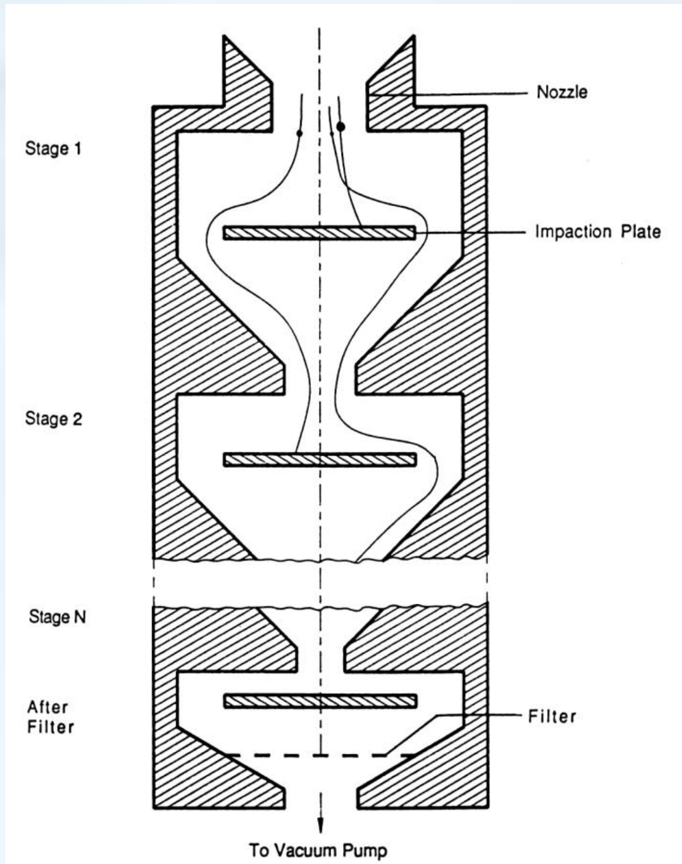
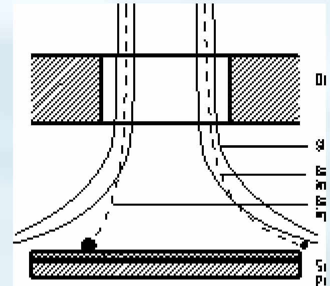


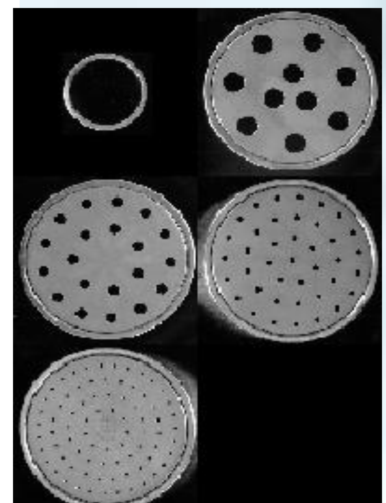
FIGURE 5.9 Cascade impactor (*a*) Schematic diagram. Reprinted with permission from *Aerosol Measurement*, by Dale Lundgren et al. Copyright 1979 by the Board of Regents of the State of Florida. (*b*) Eight stage Anderson ambient cascade impactor with nozzle plate and impaction plate shown at left.


Nozzle
Stage 1
Impaction Plate
Stage 2
Stage N
After Filter
Filter
To Vacuum Pump

(a)

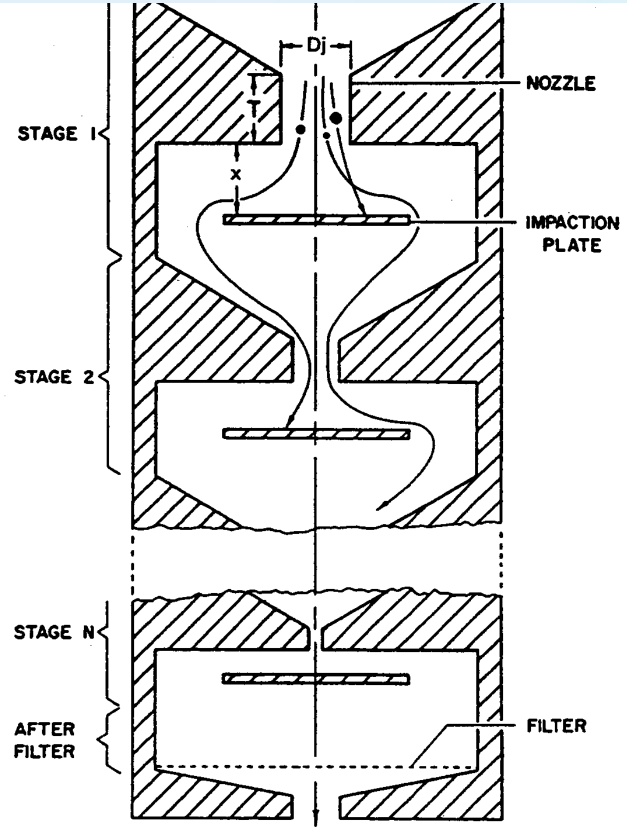


(b)



(c)

Stage	Aerodynamic size (μm)	Geometric mean (μm)
1	0.100-0.215	0.147
2	0.215-0.464	0.316
3	0.464-1.000	0.681
4	1.000-2.15	1.47
5	2.15-4.64	3.16
6	4.64-10	6.81



(a)

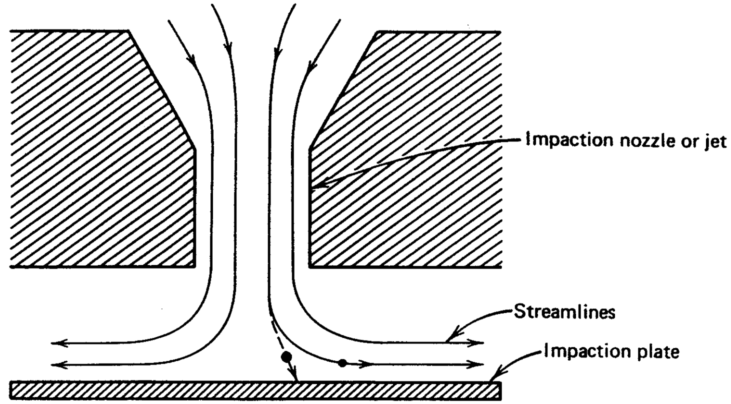
Cascade impactor. Schematic diagram. Reprinted with permission from *Aerosol Measurement*, by Dale Lundgren et al. Copyright 1979 by the Board of Regents of the State of Florida.

To decrease the cut-off diameter from stage to stage is achieved by

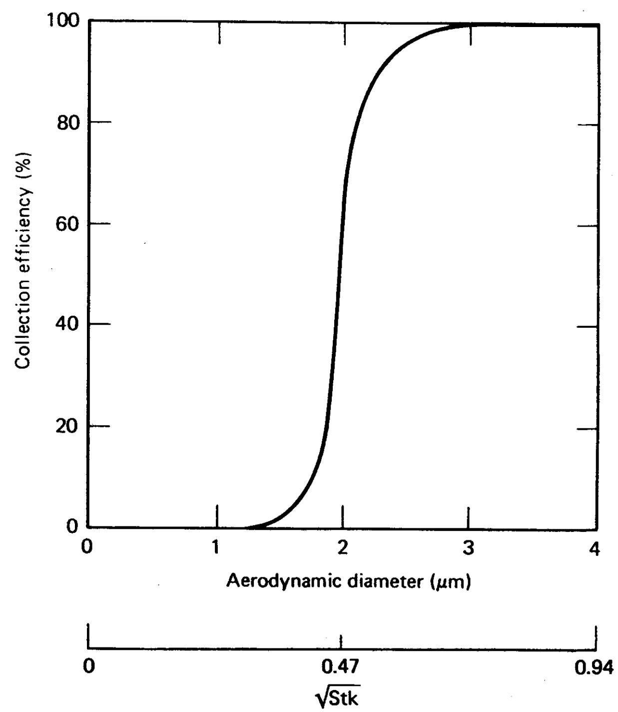
a) decreasing the nozzle diameters (increase in particle/air velocity)

b) and/or decreasing the number of nozzles

c) and/or decreasing the pressure (increase in slip correction).



Cross-sectional view of an impactor.



Typical impactor efficiency curve.

Optical Particle Counter

- Similar to photometer, but particles are isolated
  - May require dilution
- 0.065 – 20 μm
  - Practically 0.1 – 5 μm
- Some devices just count

Particle Soot Adsorption Photometer (PSAP)

three stage wavelength

Differential Mobility Particle Sizer (DMPS)

The Differential Mobility Particle Sizer (DMPS) is an instrument designed to measure aerosol size spectra down to very small size.

The Differential Mobility Particle Sizer (DMPS) and Scanning Mobility control mechanism.

It consists of a DMA (Differential Mobility Analyser), a CPC (Condensation Particle Particle Sizer (SMPS) are basically the same type of instrument with only different electronic Counter) and some electronic controlling devices, everything controlled by a PC.

Cascade Impactor Curves