3- FORCES AND INTERACTIONS

a) **Particle forces**: sub-micrometer particles tend to stick together while larger ones do readily detach.

Adhesion Forces: particles adhere to each other and to surfaces; most adhesion forces are linearly dependent on particle diameter (thus, large particles are more readily detached than small ones).

London (van de Waals) forces: weak forces that are attractive in nature and act over a short distance relative to particle dimensions (other forces such as H bonding and π-orbital are also commonly observed).

Electrostatic forces: most particles 0.1µm carry same small net charge facilitating agglomeration as opposing forces attract each other. Dipole forces may facilitate hydration of aqueous particles resulting in agglomerates. Surface tension (of a liquid layer on a particle surface) is then the main force holding such a composite together.

تحمل معظم الجسيمات 0.1 مايكرومتر نفس الشحنة الصافية الصغيرة التي تسهل التكتل حيث تجذب القوى المتعارضة بعضها البعض. قد تسهل القوى ثنائية القطب ترطيب الجسيمات المائية مما ينتج عنه تكتلات. التوتر السطحي (لطبقة سائلة على سطح جسيم) هو القوة الرئيسية التي تربط مثل هذا المركب معًا.

Detachment Forces

- Centrifugal force: related to particle rotation and proportional to particle mass and thus volume (d^3)
- Vibration: also proportional to (d^3)
- Detachment by air currents: proportional to exposed surface (d^2)
- Rebound ارتداد: particle collision with a surface - deformed upon collision

Externally applied forces

- Gravitational force
- Aerodynamic drag
- Electrostatic force
- Diffusion (if there is a concentration gradient - very important for particles smaller than 0.2 µm)
- Inertial forces (used for example for deposition by impaction)
- Thermophoretic الحراري(if there is a temperature gradient)

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b) **Particle motion** (describes the gas-particle relation; characterizes the particle diameter in regards to the medium in which it is suspended.

Free molecular regime: sub-micrometer particles, especially <0.1µm, are affected by the motion of individual gas molecules;

The continuous regime: larger particles can be treated as being submerged in a continuous gaseous medium (characterized by a Knudsen number >1,);

The transition (or slip) regime: intermediate size particles can usually be treated by an adjustment of equations from the continuum regime (requires Cunningham slip correction factor,);

Reynolds Number: describes the onset of turbulence and is the ratio of the inertial force of the gas to the friction force of the gas moving over the surfaces:

$$Re = \rho_g . v . d_P / \eta$$

where: **v**, velocity of the gas [m/s]
η, dynamic gas viscosity [Pa·s] = [N·s/m2] = [g/(m·s)]
ρ_g is gas density [g/m3]
d_P, characteristic diameter of the particle [m]

At normal temperature and pressure (NTP which is 20°C at 101kPa corresponding to 1atm) Re can be simplified to: $\mathbf{Re = 6.5 \cdot v \cdot d_P}$

Gas Diffusion coefficient it is the result of the Brownian motion and results in net movement from regions of higher to regions of lower concentrations. A general note: remember always to correct for temperature, pressure, volume, etc, when measurements are conducted for conditions different to standard.

$$D = -\left(\frac{3\cdot\sqrt{2}\cdot\pi}{64\cdot N\cdot d_{molec}^{2}}\right)\cdot\sqrt{\frac{R\cdot T}{M}}$$ [m²/s]

Flux J: $J = -D\cdot\frac{\partial N}{\partial x}$ [m/s]

The average velocity of a gas molecule:

$$\bar{v} = \bar{v}_r\cdot\sqrt{\frac{T\cdot M_r}{T_r\cdot M}}$$ [m/s]

Mean free path (λ):

$$\lambda = \lambda_r\cdot\frac{101.3}{P}\cdot\frac{T}{293.15}\cdot\frac{1+S/293.15}{1+S/T}$$ [m]

Gas viscosity

$$\eta = \eta_r\cdot\frac{T_r+S}{T+S}\cdot\left(\frac{T}{T_r}\right)^{3/2}$$ [N·s/m²]

N number of gas molecules per unit volume		$[1/cm^{-3}]$
d_{molec}, molecular collision diameter		[m]
R, gas constant	8.315	[J/(mol·K)]
D, diffusion in a concentration gradient		[m²/s]
(D_{air} at NTP) = 0.18cm²/s)		
(D for air: 3.7·E^{-8} cm²/s)		
x, distance		[m]
T, temperature		[m]
T_r = 293K		
v_r, particle velocity		[m/s]
reference values for air at NTP: $\bar{v}_r$ = 463 m/s		
M, molecular weight of gas molecule		[g/mol]
M_r = 28.9 g/mol		
λ_r, mean free path		[m]
S, Sutherland interpolation constant		[-]
η_r, viscosity of gas		[Pa·s]

Particle diffusion likewise connected to Brownian motion, it is dependent on the size and shape of the aerosol particle, resulting in slower diffusion of larger particles than

$D = k.T.\ C_c / 3.\ \eta.\ \pi\ .d_P$ **[m²/s]**

The root mean square distance that a particle can travel in time t is

$$x_{rms} = \sqrt{2.D.t}$$ **[m]**

where:

D, particle diffusion coefficient		[m2/s]
k, Boltzmann constant	1.381·E^{-23}	[J/K]
T, temperature		[K]
C, Cunningham slip correction factor		[-]
η, viscosity of gas		[Pa·s]
t, time		[s]

Knudsen number: It relates the gas molecular mean free path to the physical dimensions of the particle (usually its radius). The mean free path of a particle, defined as the distance between collisions of gas molecules, is depended on temperature and pressure. Thus, the Knudson number (again a dimensionless quantity), relates the gas molecular mean free path to the physical dimension of the particle; thus, **Kn is an indicator of particle size.**

$Kn = 2\lambda / d_p$ [-]

Kn <<1, continuum flow
Kn >>1, free molecular flow
0.4 < Kn < 20, slip regime

c)Particle motion in an electric field: For a particle with a total charge equal to n times the elementary unit of charge e, the electrostatic force is (Note: Electrostatic forces are particularly effective for sub-micrometer particles): Applications: electrostatic precipitators; size classification.

electrostatic precipitators; size classification

$$F_{elec} = n \cdot e \cdot E$$

Terminal velocity in electric field: $F_{elec} = F_{drag} \Rightarrow$

$$\frac{n \cdot e \cdot E \cdot C_c}{3 \cdot \pi \cdot \eta \cdot d_p} = \frac{3 \cdot \pi \cdot \eta \cdot \chi \cdot v \cdot d_p}{C_c}$$

$$v_{elec} = \frac{n \cdot e \cdot E \cdot C_c}{3 \cdot \pi \cdot \eta \cdot d_p} \qquad \text{[m/s]}$$

Mechanical particle mobility B:

$$B = \frac{C_c}{3 \cdot \pi \cdot \eta \cdot d_p} \qquad \text{[s/g]}$$

$$v_{elec} = n \cdot e \cdot E \cdot B \qquad \text{[m/s]}$$

Particle electrical mobility Z:

$$Z = n \cdot e \cdot B \qquad [\text{m}^2/(\text{V}\cdot\text{s})]$$

$$v_{elec} = Z \cdot B \qquad \text{[m/s]}$$

e, unit charge
n, number of unit charges
E, electrical field strength
C_c Cunningham slip correction factor
π, circular constant
χ, dynamic shape factor
d_p physical particle diameter
η, viscosity of medium
V_{elec}, electric field velocity

d) Particle motion in other force fields (are generally much weaker than gravitational or electrostatic forces); these forces are caused by the presence of a:

- thermal gradient (thermophoresis and photopheresis)
- electromagnetic radiation pressure
- acoustic pressure
- diffusiophoresis

4- INSTRUMENTATION AND MEASUREMENTS

4-1 Measurement techniques

What to measure?

- particle mass;
- particle number;
- mass or number size distribution;
- chemical composition;
- biological composition;
- radioactivity;
- combination of these;

How to measure? In general, each aerosol measurement technique covers a unique range of particle characteristics such as:

- concentration;
- size;
- shape;
- chemical or biological composition;

Choosing the proper instrument for a particular application is of critical importance. A thorough understanding of the principles and limitations of each measurement method is essential.

4-1-1 Type of aerosol measurements

- sample collection and real time measurements (on site);
- active (e.g., pump) and passive sampling (exposure of collecting device);
- personal and area sampling (in either case should be representative);
- continuous measurements or grab sampling (e.g., once an hour);
- sampling from flows - isokinetic sampling;

Detection is a two-stage process:
i) measurement for the determination of the quantity;
ii) data deconvolution for the determination of the quality.

a) Mass measurement techniques

Sample collection methods (static):

- Filter collection;
- Inertial and gravitational collection;
- Diffusional deposition;
- Electrostatic deposition;

b) Number concentration measurement techniques - concentration of atmospheric particles is most commonly performed using (both techniques provide no information about the size distribution):

- condensation nucleus counters;
- aerosol electrometers;

c) **Size distribution** measurement techniques: for atmospheric particle size classification it includes:

- optical particle counters (inlets determines which sort of particles may be measured);
- electrostatic classifiers;
- diffusion batteries;

d) **Combination of physical measurement techniques:** Information on particle size distribution is generally obtained by combining a dynamic aerosol detection technique with a size classification technique.

4-2 Filter collection: Filter collection is conducted for further:

- gravimetric analysis (mass – standard filters do not allow microscopic analysis)
- microscopic analysis (shape, number, elemental composition, morphology)
- microchemical analysis (chemical composition; organic and inorganic; elements and compounds)
- radioactivity measurements.

Filter classification - Filters used for aerosol sampling are:

- fibrous filters;
- porous-membrane filters;
- straight-through pore membrane filters;
- granular-bed filters.

Filtration mechanisms - Mechanisms causing particle deposition are:

- diffusion;
- inertial impaction;
- interception;
- gravitational settling.