ME 437/ME 537

PARTICLE TRANSPORT, DEPOSITION AND REMOVAL

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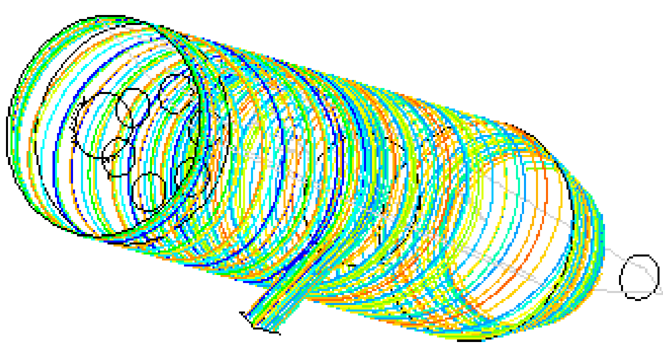
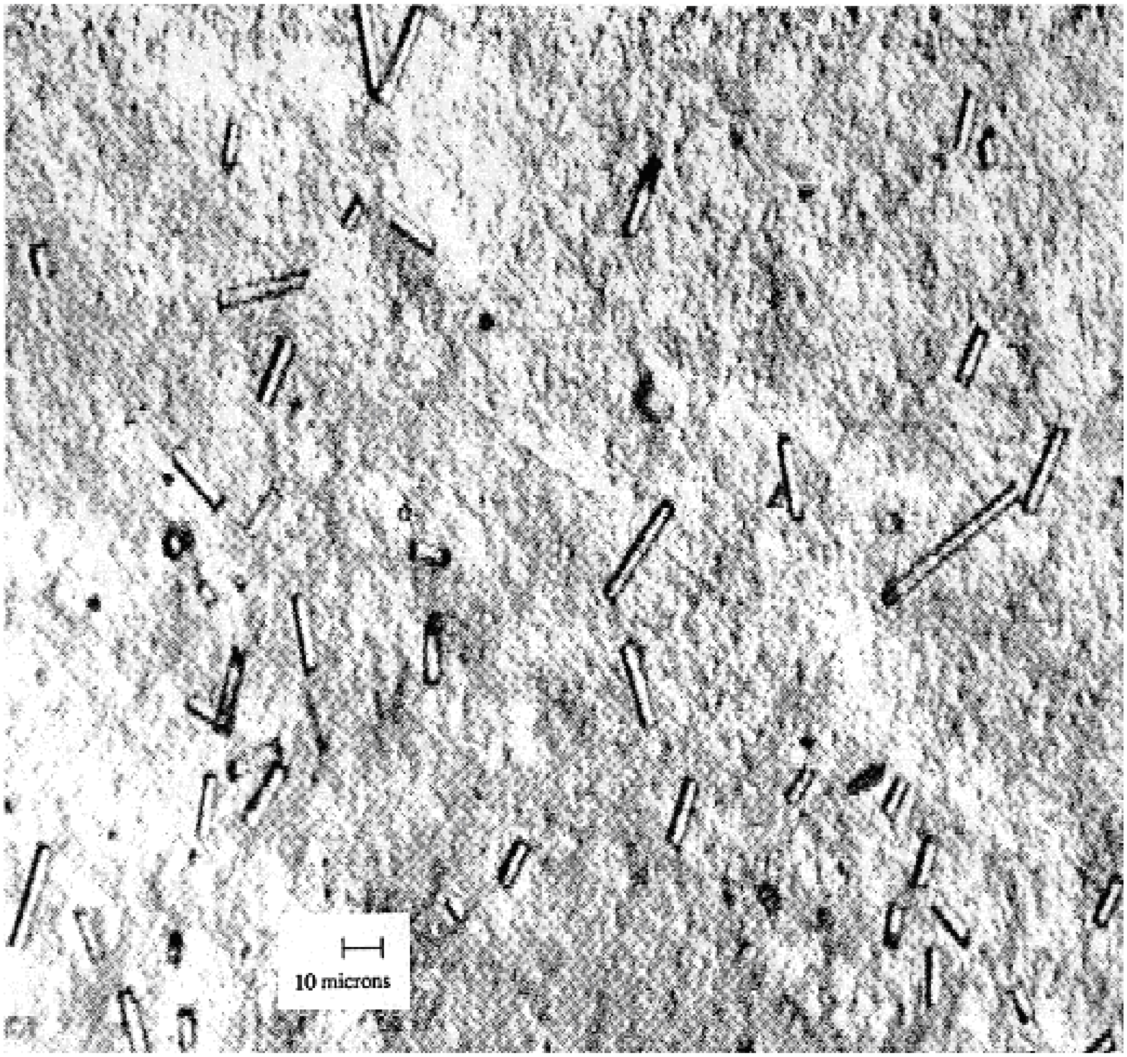
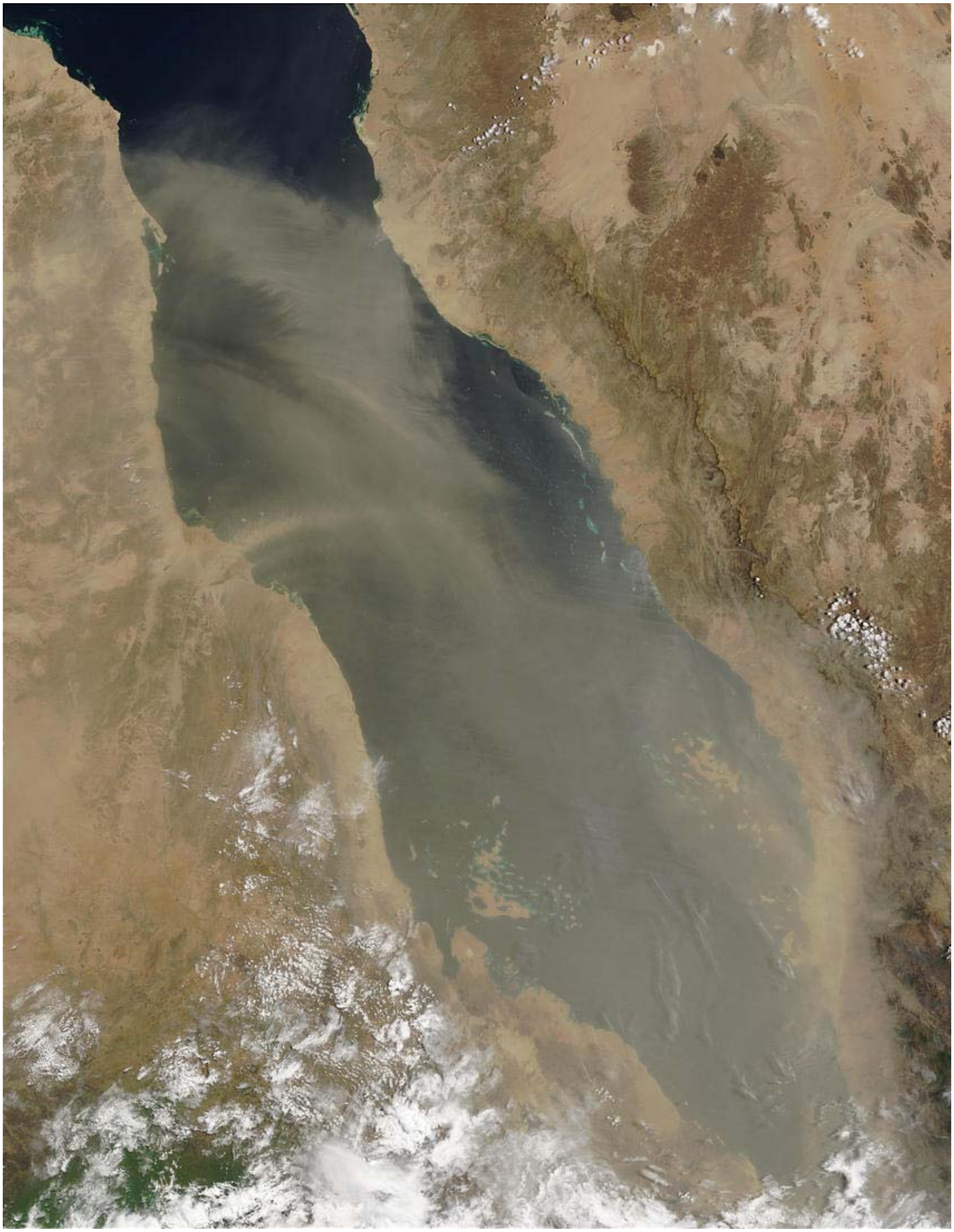
Air pollution and smog.



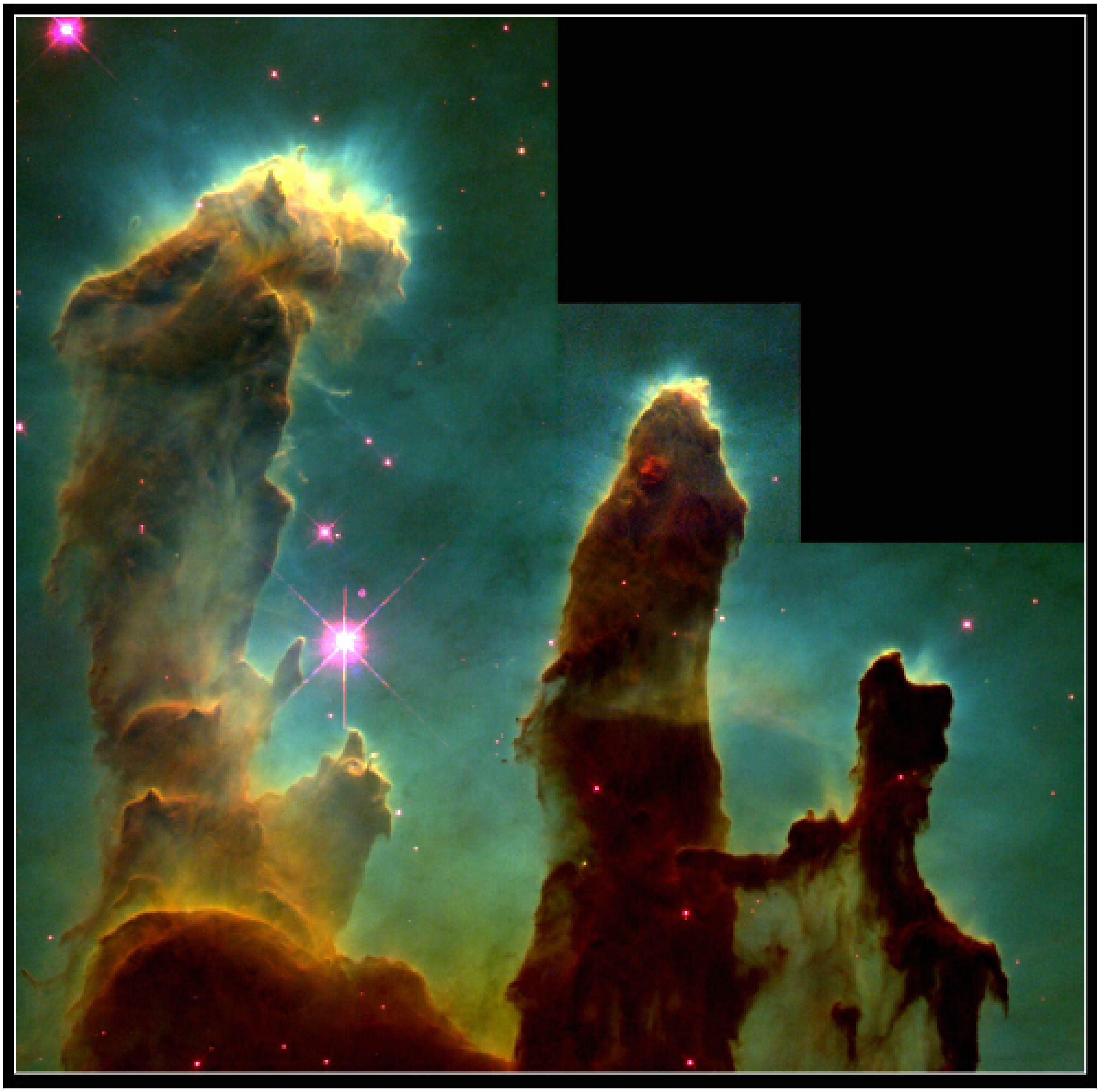
Particle trajectories in a hot gas filtration vessel.



Sample glass fiber particles.



Dust storm over the red sea.



Birth place of stars.

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INTRODUCTION TO AEROSOLS

Definition: Aerosol is a suspension of solid or liquid particles in a gas. Dust, smoke, mists, fog, haze, and smog are various forms of common aerosols. Aerosol particles are found in different shapes (isometrics, platelets, and fibers) and different sizes. For irregular shaped particles, different equivalent diameters are defined. Examples of equivalent diameters are:

- Equivalent area diameter,
- Feret's diameter (maximum distance edge to edge);
- Stoke's diameter (diameter of a sphere with the same density and the same velocity as the particle);
- Aerodynamic diameter (diameter of a sphere with the density of water and the same velocity as the particle).

The range of diameters of common aerosol particles is between 0.01 and 100 μm. The lower limit of 10 nm roughly corresponds to the transition from molecule to particle. Particles larger than 100 μm normally do not remain suspended in air for a sufficient amount of time. Noting that the mean free path for air is about 0.07 μm and visible light has a wavelength band of 0.4 – 0.7 μm, the mechanical and optical behaviors of particles are significantly affected by their size.

Particles greater than 5 – 10 μm are usually removed by the upper respiratory system. But particles smaller than 5 μm can penetrate deep into the lung and become a health hazard. Typical ranges of values for aerosol parameters for aerosols are listed in Table 1. The corresponding values for air (N_2) are also shown in this table for comparison.

Table 1 - Parameters of Aerosol in the Atmosphere

	Aerosols	Air
Number Density (Number/cm^3)	100-10^5	10^{19}
Mean Temperature (K)	240 – 310	240 – 310
Mean Free Path	Greater than 1m	0.06 μm
Particle Radius	0.01 – 10 μm	2×10^{-4} μm
Particle Mass (g)	10^{-18} - 10^{-9}	4.6×10^{-23}
Particle Charge (in Elementary Charge Units)	0 – 100	Weakly Ionized Single Charge

The important relevant dimensionless groups relevant the motion of aerosols are listed in Table 2.

Table 2 – Dimensionless Groups

Knudsen Number	$Kn = \frac{2\lambda}{d}$
Mach Number	$M = \frac{\lvert \mathbf{v}^p - \mathbf{v}^f \rvert}{c^f}$
Schmidt Number	$Sc = \frac{\nu}{D} = \frac{n^f \lambda d^2}{4}$
Brown Number	$Br = (\frac{\overline{v^{p,2}}}{\overline{v^{f,2}}})^{1/2} = \frac{\lvert \overline{v'^p} \rvert}{\lvert \overline{v'^f} \rvert}$
Reynolds Number	$Re = \frac{\lvert \mathbf{v}^p - \mathbf{v}^f \rvert d}{\nu} = \frac{4M}{K_n}$

Here the following symbols are defined:

λ = Mean Free Path
d = Particle Diameter
$\mathbf{v}^p$ = Particle Velocity
$\mathbf{v}^f$ = Fluid (Air) Velocity
c^f = Speed of Sound

ν = Kinematic Viscosity
D = Diffusivity
v' = Thermal Velocity
n = Number Density

Here superscript "^{f}" corresponds to fluid and superscript "^{p}" denotes particle.

In these equations the root mean square fluctuation velocity is given by

$$\lvert v'^f \rvert = (8kT / \pi m^f)^{1/2}$$

and

$$\nu = 0.5 c^f \lambda$$

The mean free path of the gas is given as

$$\lambda = \frac{1}{\sqrt{2}\pi n d_m^2} = \frac{kT}{\sqrt{2}\pi d_m^2 P}$$

Here n is the gas number density, d_m is the gas molecule (collisional) diameter, $k = 1.38\times10^{-23}$ J/K is the Boltzmann constant, P is pressure, and T is temperature. For air, $d_m = 0.361\,\text{nm}$ and

$$\lambda(\mu m) = \frac{23.1T}{P}, \qquad \text{P is in Pa, and T is K.}$$

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Table 3. Aerosol Characteristics

Particle Diameter, μm: 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, 10^{0}, 10^{1}, 10^{2}, 10^{3}, 10^{4}

Electromagnetic Wave		← **x-Ray** →← **UV** → **Vis** ← **Infrared** →← **Microwaves**
Definition	**Solid**	← **Fume** →← **Dust** →
	Liquid	← **Mist** →← **Spray** →
Soil		← **Clay** → **Silt** ← **Sand** → **Gravel**
Atmospheric		← **Smog** → **Cloud/Fog** **Mist** ← **Rain** →
Typical Particles		← **Viruses** → ← **Bacteria** → **Human Hair**; ← **Smoke** →← **Coal Dust** → **Beach Sand**
Size Analysis Method		← **Microscope** →; ← **Electron Microscope** → ← **Sieving** →; **x-Ray Diffraction**; ← **Ultra Centrifuge** →← **Sedimentation** →
Gas Cleaning		← **Ultrasonics** →← **Settling Chamber** →; ← **Centrifugal** →; ← **Liquid Scrubber** →; ← **Air Filter** →; ← **HE Air Filter** →← **Impact Separators** →; ← **Thermal Separators** →; ← **Electrostatic Separators** →

		10^{-4}	10^{-3}	10^{-2}	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
Diffusion Coeff. cm^2/s	**Air**		5×10^{-2}	5×10^{-4}	10^{-5}	3×10^{-7}	2×10^{-9}	2×10^{-10}	2×10^{-11}	
	Water		5×10^{-6}	5×10^{-7}	5×10^{-8}	5×10^{-9}	5×10^{-10}	5×10^{-11}	5×10^{-12}	5×10^{-13}
Terminal (S=2) Velocity cm/s	**Air**		10^{-6}	1.5×10^{-5}	2×10^{-4}	7×10^{-3}	0.6	50	600	2.5×10^{3}
	Water		10^{-10}	6×10^{-9}	6×10^{-7}	6×10^{-5}	6×10^{-3}	0.6	12	58

10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4}

Particle Diameter, μm