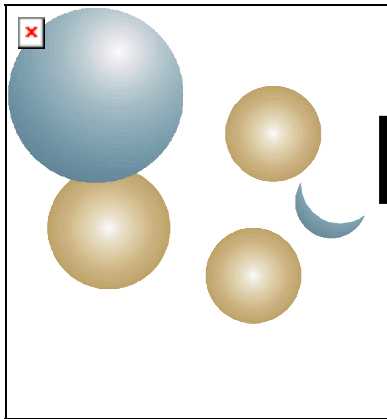




Particle Physics



Outline



- **Particle Basics**
- **Particle Mechanics**
- **Filters**
- **Light Scattering by Particles**
- **Summary**

Why Are Particles Important?



- **Money**
 - **Particles can impact yield**
 - Semiconductor manufacturing
 - Hard disk drive manufacturing
 - **Suppliers can demand more for their product if it has fewer particles**
 - **Reliability**
 - **Throughput**
- **Government regulation**
- **Health concerns**

Particle Basics



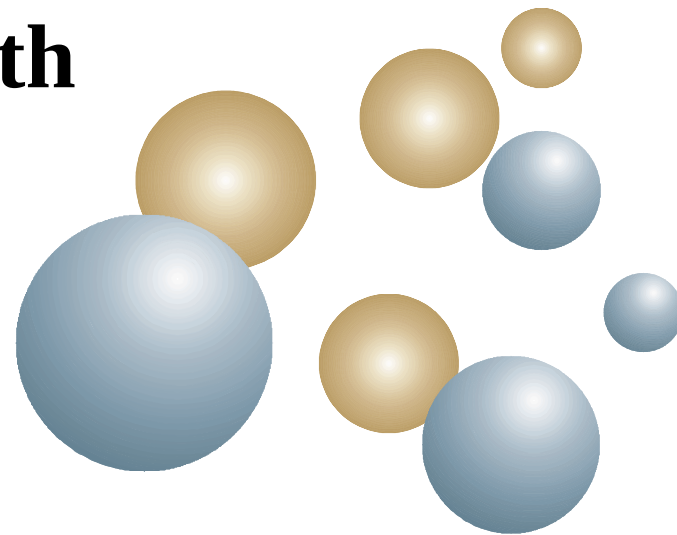
- **Size**
- **Composition**
- **Shape**
- **Sources of particles**



Particle Size



- Size typically expressed in microns (μm)
- Micron is 1/1 millionth of a meter
- 25,400 μm per inch

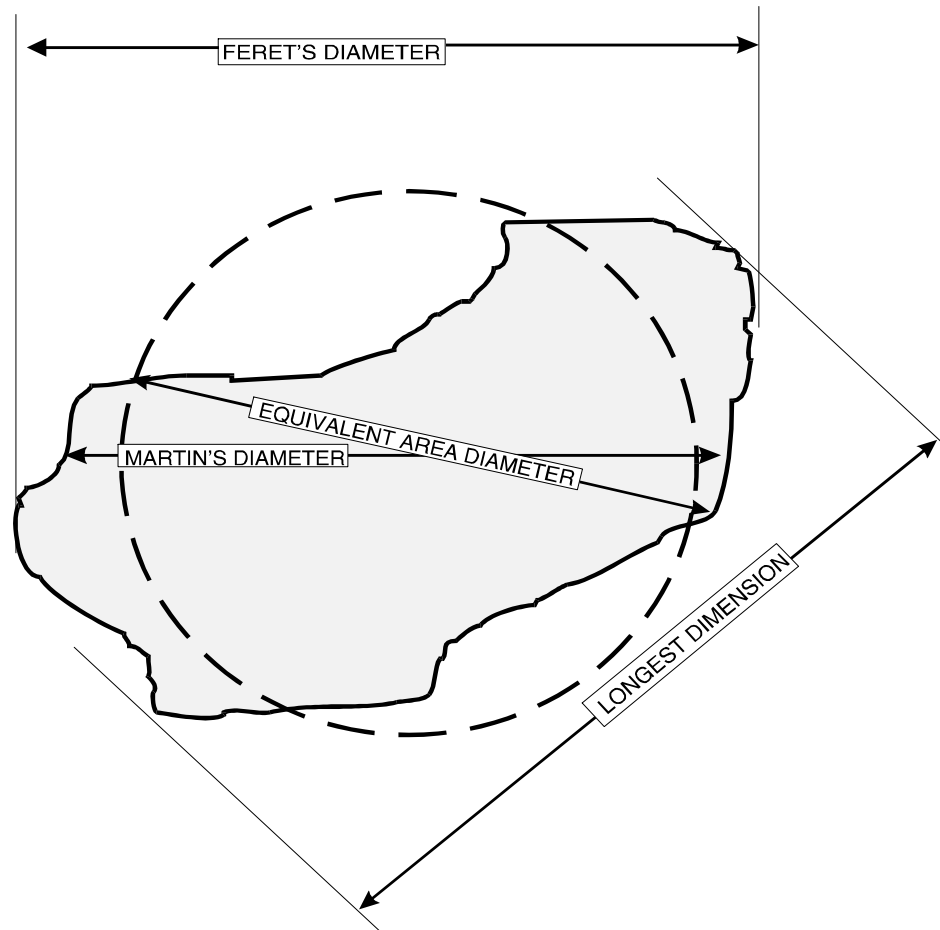


Typical Particle Sizes



- **Hair** 50-150 μm
- **Visible** 50 μm
- **Flu virus** 0.07 μm
- **Pollen** 7 to 100 μm
- **Sneeze particles** 10 to 300 μm
- **Dust** 0.1 to 100 μm
- **Bacteria** 1.0 to 10 μm

Particle Size Measurements



Particle Types



- **Particle**
 - Single particle, regular shape, similar material throughout
- **Aggregate**
 - Group of particles held together by strong atomic or molecular forces (concrete)
- **Agglomerate**
 - Group of particles held together by weaker forces of adhesion or cohesion (dirt clod)
- **Flocculate**
 - Weaker still

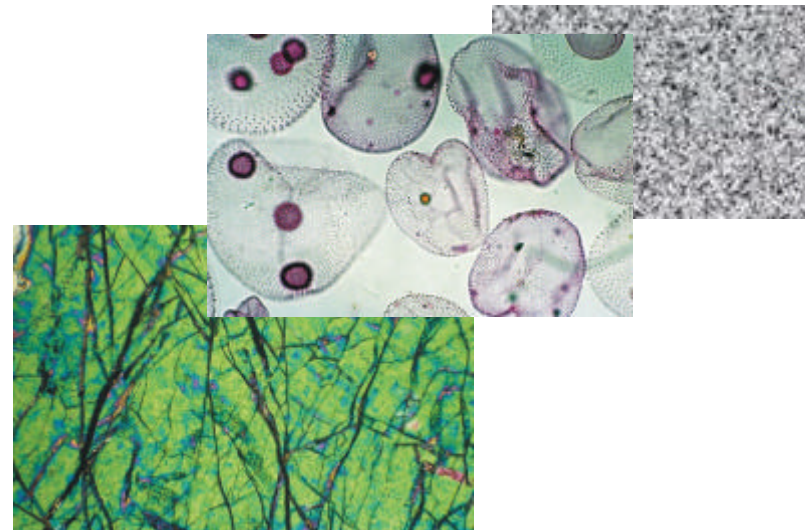
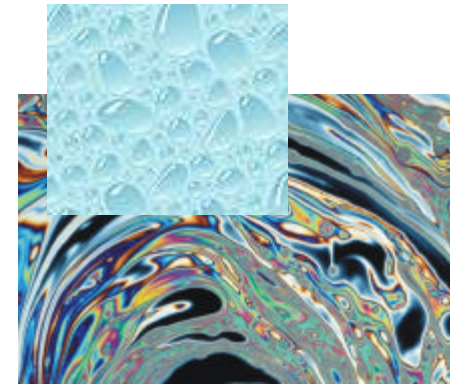
Particle Composition



- **Depends on where you are interested**

- Atmosphere

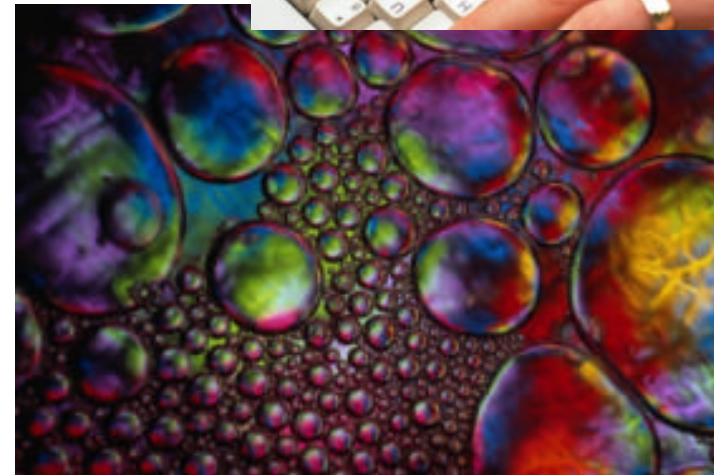
- Water and ice
 - Dirt (silicon, iron, and aluminum compounds)
 - Oxides of nitrogen and sulfur
 - Carbon
 - Organic material
 - Pollen
 - Bacteria
 - Virus
 - Plant material



Particle Composition In Cleanrooms



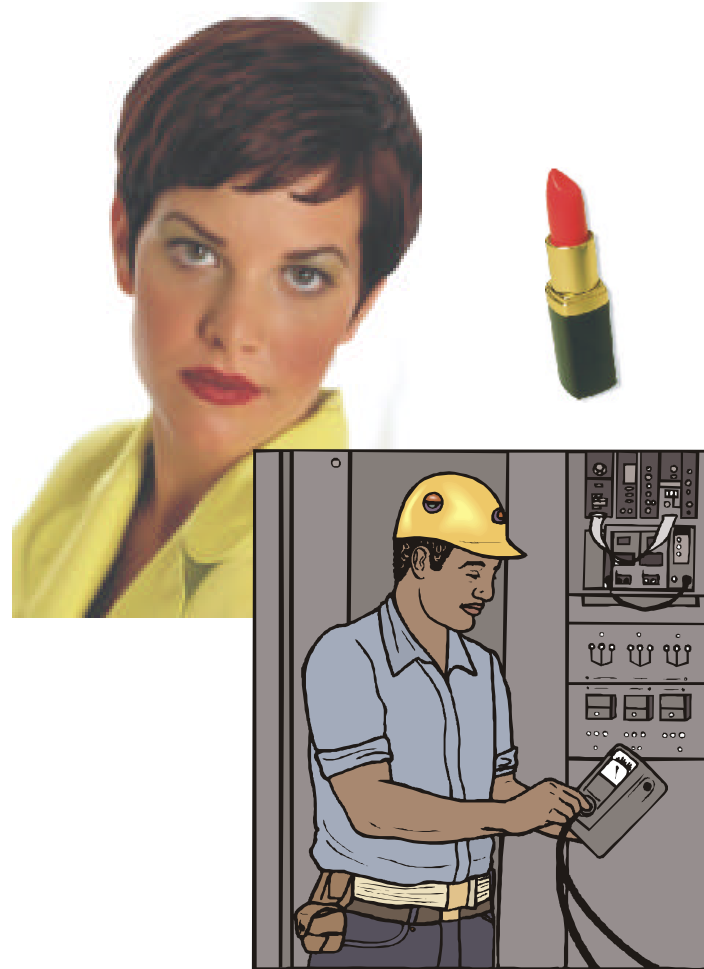
- **Most particles from human activity**
 - Skin
 - Shed about 1 oz of particles a day
 - Exhaled particles
 - Drink water before entering cleanroom
 - Movement
- Manufacturing
 - Chemicals
- Bacteria
 - Mostly in DI water systems



Particle Sources: Flaking



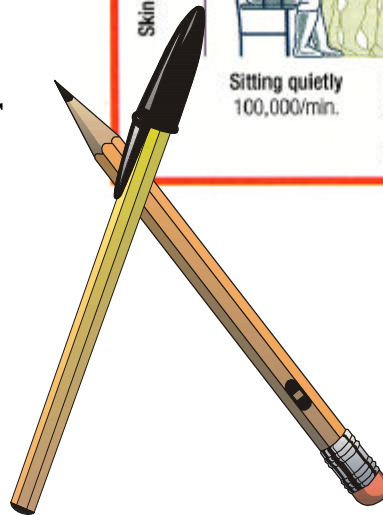
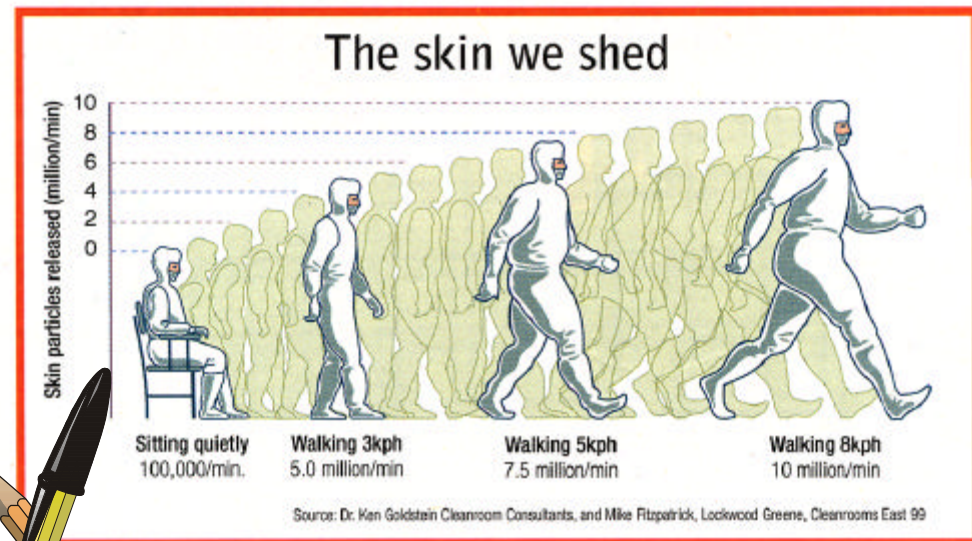
- Skin
- Cosmetics
- Construction materials
- Build up inside of process tools



Particle Sources: Friction



- **Almost any process where surfaces slide against each other will generate particles**
 - Walking
 - Machine vibration
 - Writing with pencil or even ball point pen
- **Tends to make relatively large particles**



Particle Sources: Friction



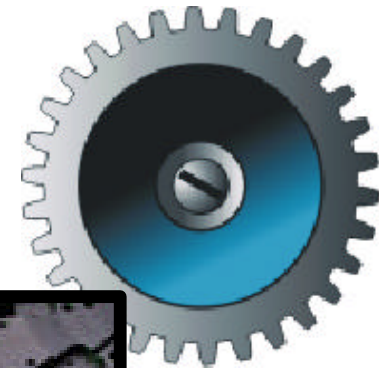
- **Robots**

- Designed to minimize particle generation
- Usually caused by malfunction of wear and tear
- Drive belts, motors, etc. isolated from clean area

- **Vacuum wands**

- **Screws**

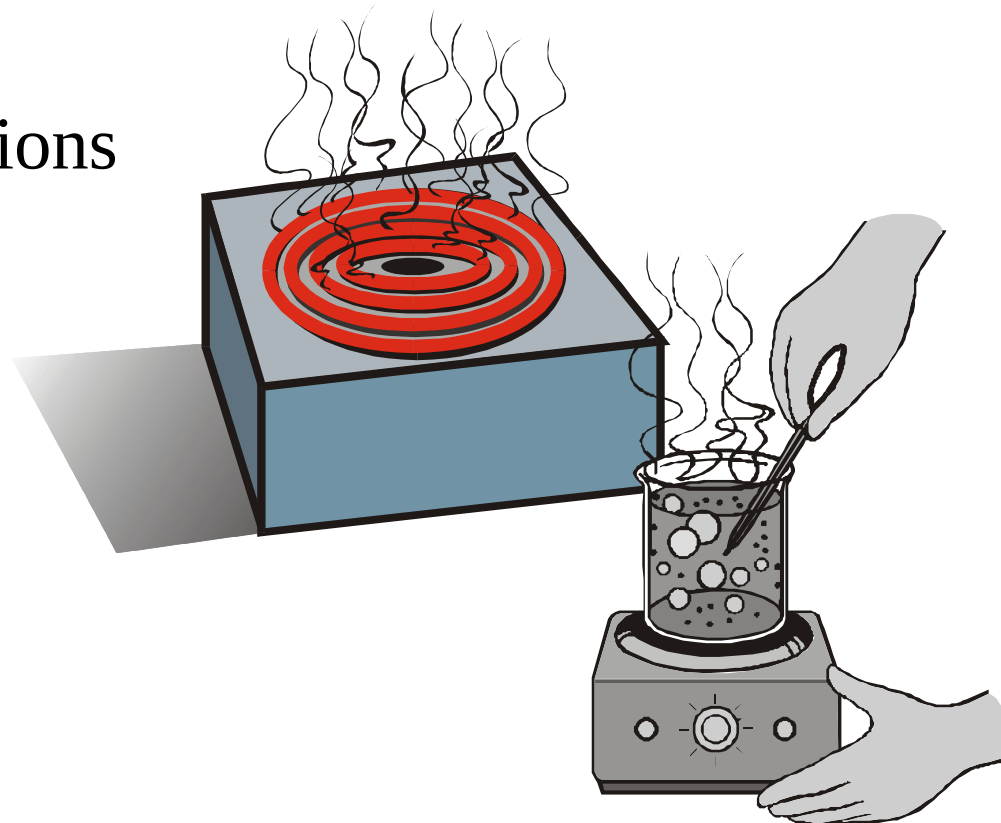
- **Doors**



Particle Sources: Heat



- **Hot surfaces tend to generate particles**
 - Some flaking
 - Chemical reactions



Particle Sources: Combustion



- **Smoke is particles**
 - Smokers exhale a lot of particles
 - Large source of atmospheric particles
 - Carbon
 - Sulfur compounds
 - Oxides of nitrogen
 - Construction in cleanroom



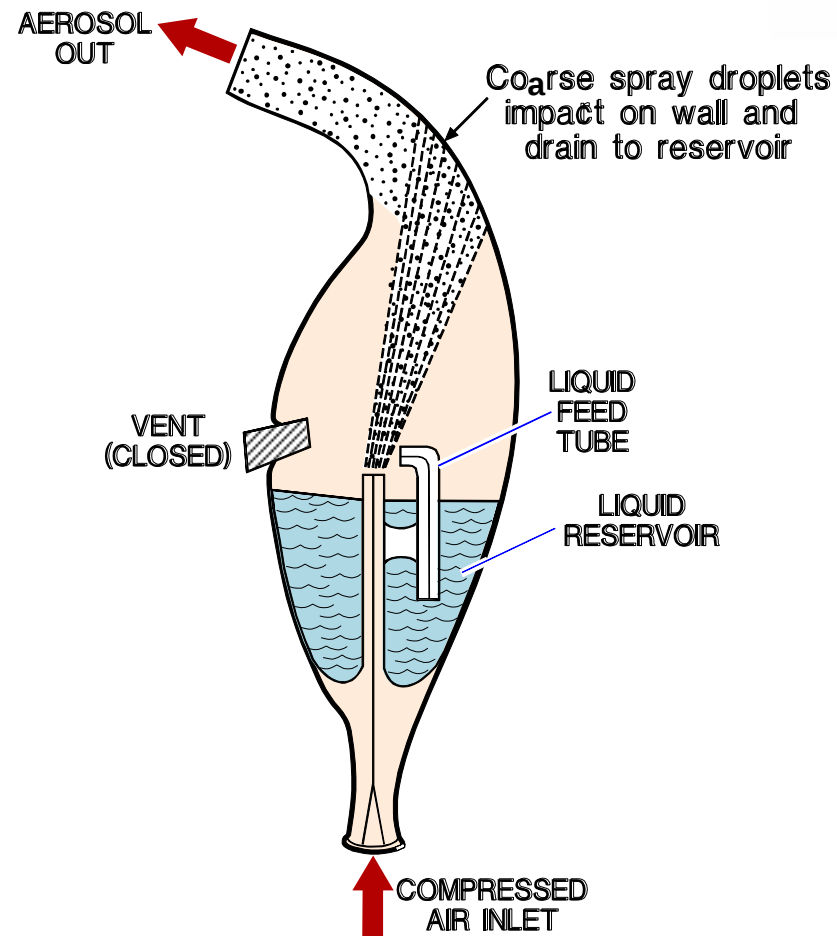
Particle Sources: Nucleation



- **Small drop of water is formed containing some non-volatile material**
- **Water evaporates**
- **Non-volatile material forms particle**
 - Salt near ocean
 - Generate test particles



Nebulizer



Particle Sources: Assorted



- **Stirring up the dust**
 - Wiping down cleanroom
 - Walking
 - Changing air flow
 - Banging the plumbing
- **New plumbing and fittings**
- **Chemical reactions**



Particle Sources: Assorted



- **Valves**
 - Trap particulates take longer to clean up
- **Pumps**



Typical Particle Concentrations



- **Normal indoor air has around 1,000,000 particles/ft³ > 0.5 μ m**
- **Marine surface 11 million/ft³ > .002 μ m**
- **Continental background 55 million/ft³ > .002 μ m**
- **Urban average 55 billion/ ft³ > .002 μ m**



209E Cleanroom Classifications



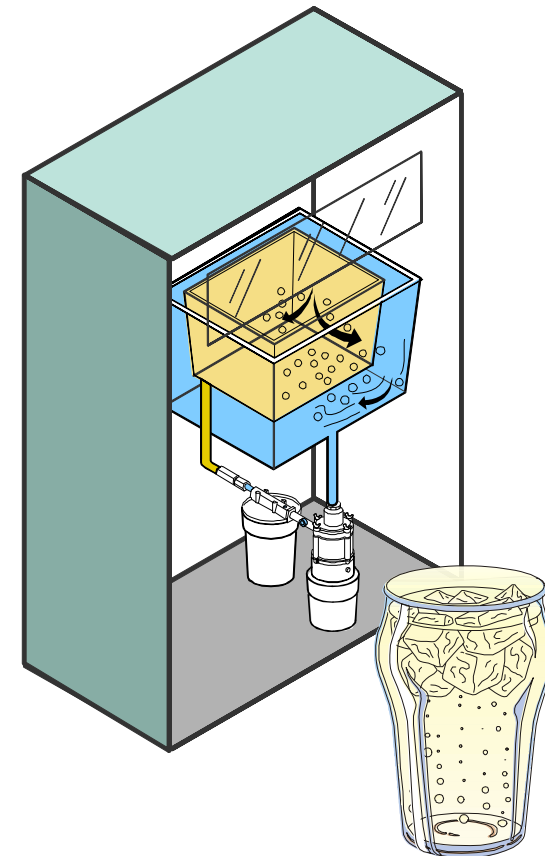
Particle size (µm)	0.1	0.2	0.3	0.5	1
Cleanroom class					
0.1	3	na	na	na	na
1	35	7	3	1	na
10	350	70	30	10	2
100	na	700	300	100	20
1000	na	na	3000	1000	200
10,000	na	na	na	10000	2000

Particles per cubic foot

Typical Liquid Concentrations



- **State of the art ultra-pure water system**
 - <0.5 particles/ml larger than 0.05 μm
- **HF acid bath at rest**
 - < 10 particles/ml larger than 0.1 mm
- **Hot acids**
 - Hundreds/ml larger than 0.3 mm
- **Drinking water**
 - About 20 particles/ml larger than 2 mm



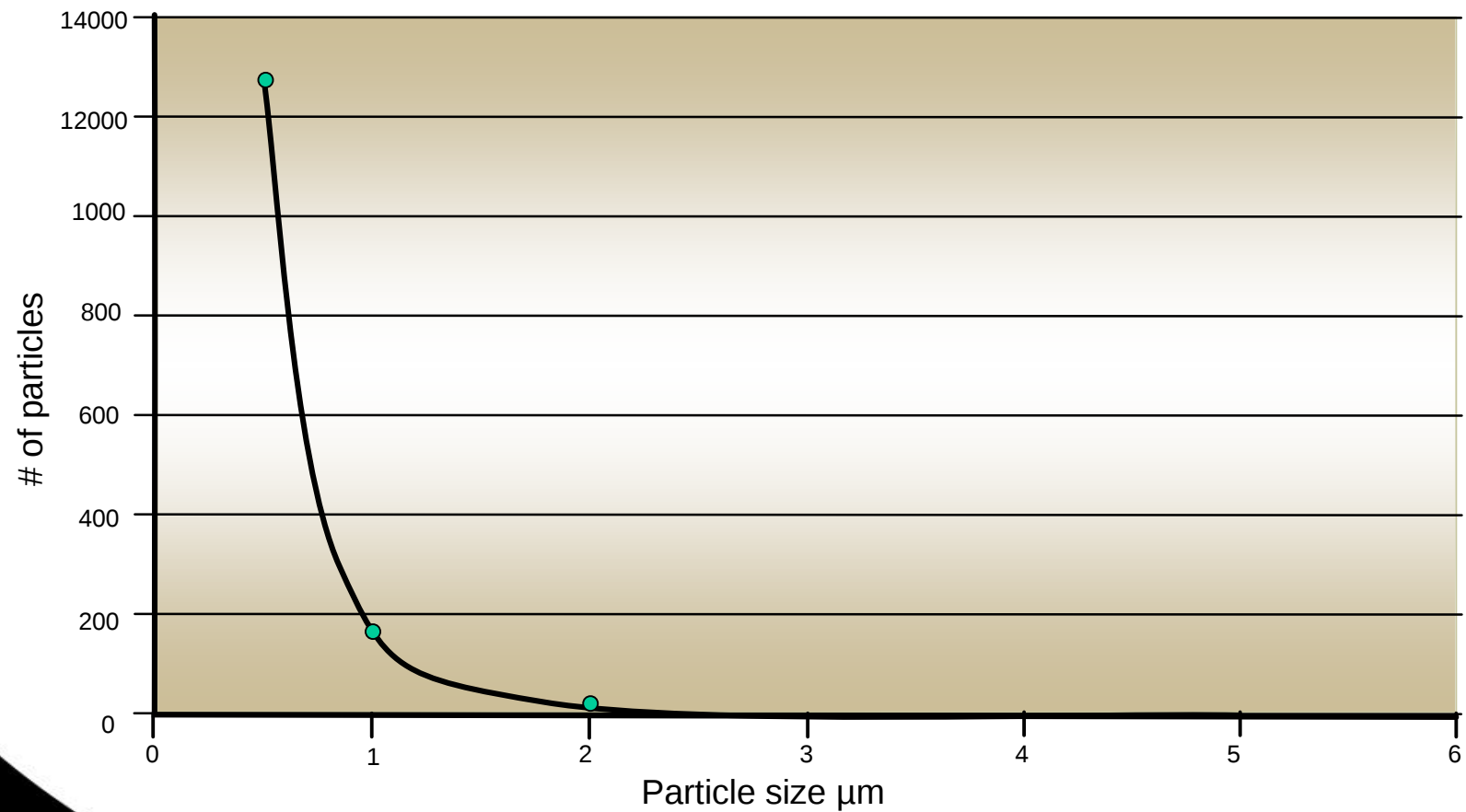
Typical Size Distributions



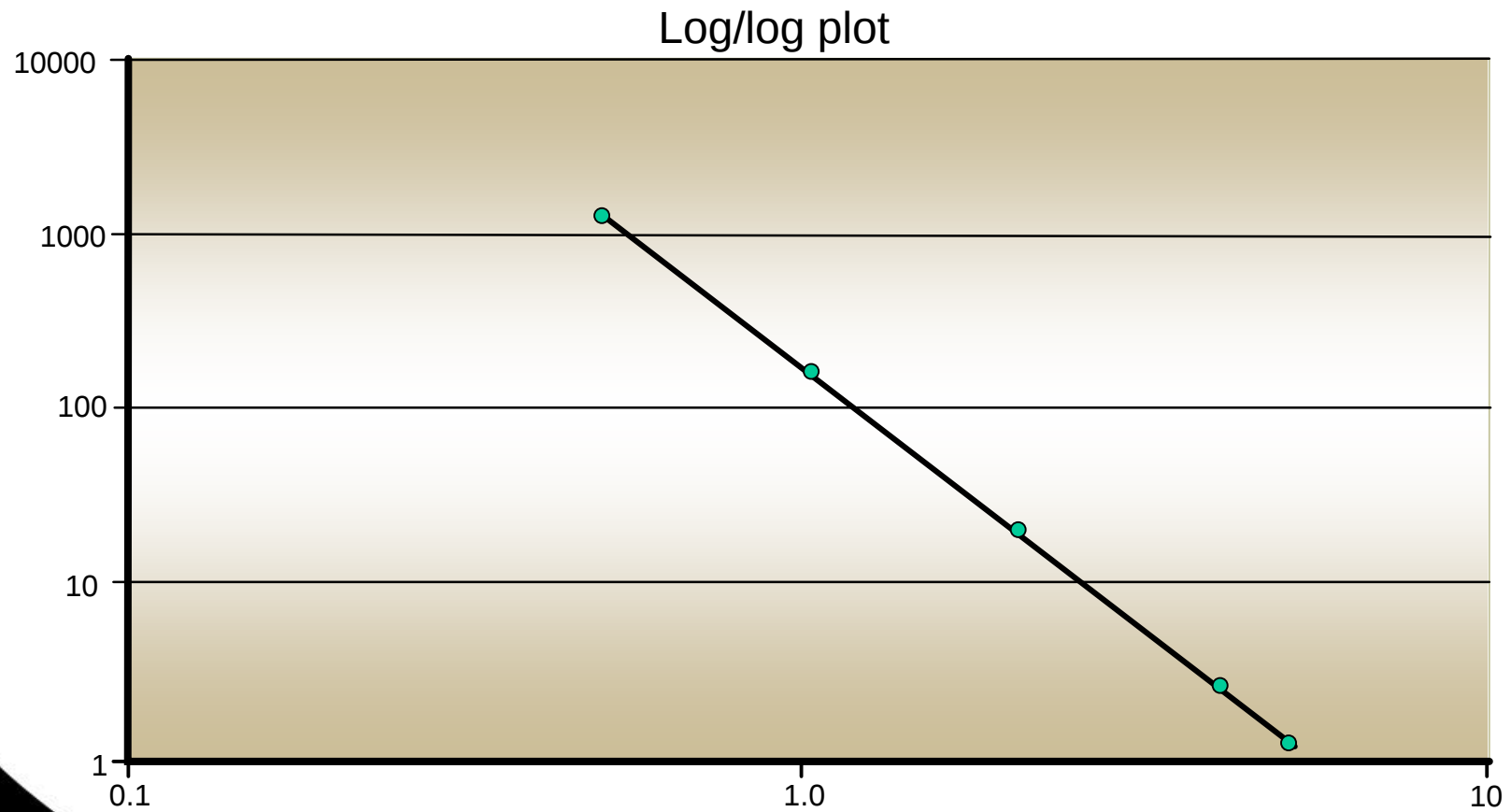
- Cleanroom standards assume power law distribution proportional to $1/\text{diameter}^{2.2}$
- Liquid distributions range from $1/(\text{diameter})^2$ to $1/(\text{diameter})^{4.5}$
 - $1/(\text{diameter})^3$ is good rule of thumb for most liquids



$1/\text{diameter}^3$ Distribution



$1/\text{diameter}^3$ Distribution



Effect of Size Distribution on #'s of Particles



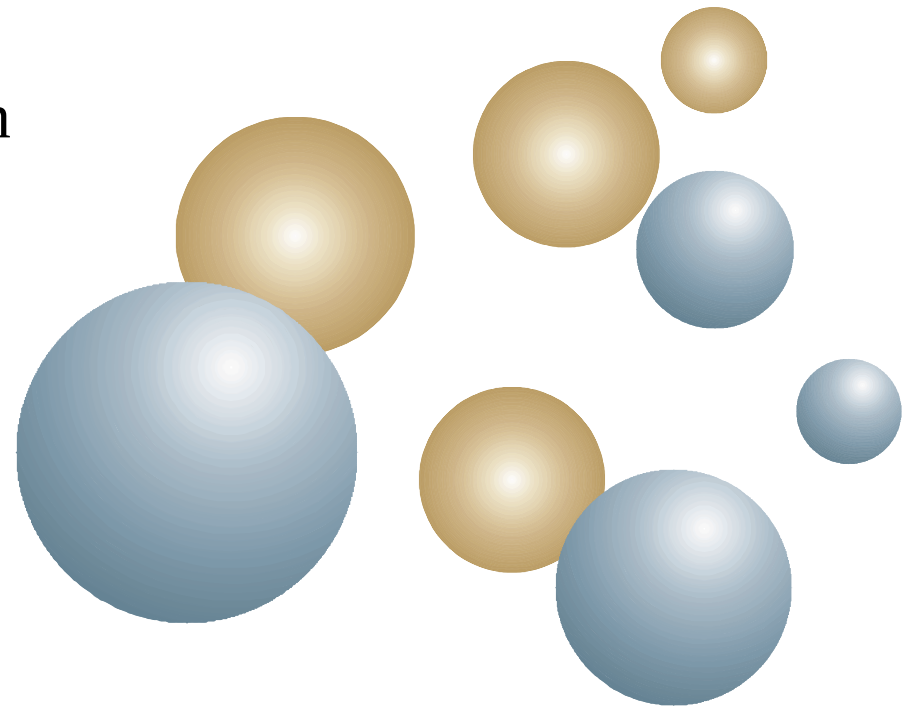
- Assume $1/(\text{diameter})^3$ distribution
- Drinking water has 20 particles/ml $> 2 \mu\text{m}$
- How many particles at $> 0.5 \mu\text{m}$?
 - $= (\text{number of particles} > 2 \mu\text{m}) * 1/(\text{ratio of diameter})^3$
 - $20 * 1/(.25)^3 = 1280 \text{ particles} > 0.5 \mu\text{m}$



Particle Mechanics



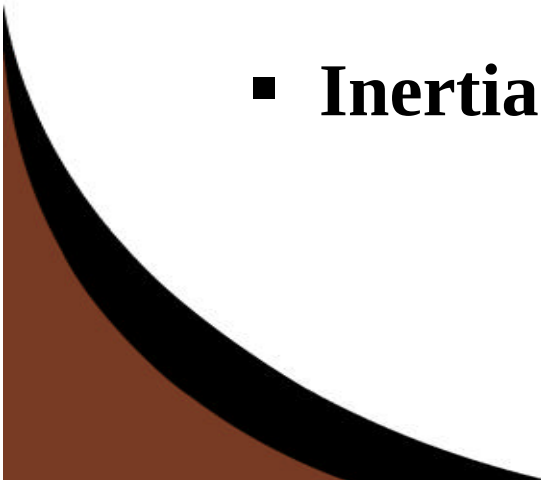
- **Forces on particles**
- **Particle movement**
 - Viscous transportation
 - Particle “slip”
 - Brownian motion
- **Settling velocity**
- **Diffusion**



Forces on Particles



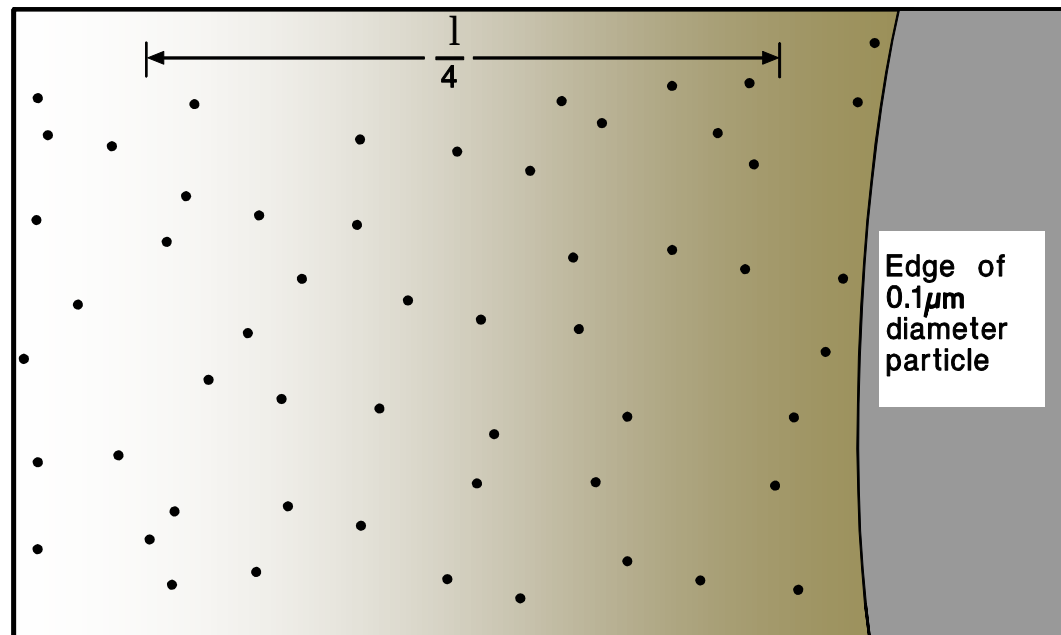
- **Gravity**
- **Electrostatic forces**
- **Thermophoretic forces**
- **Viscous forces**
- **Inertia**



Viscous Forces



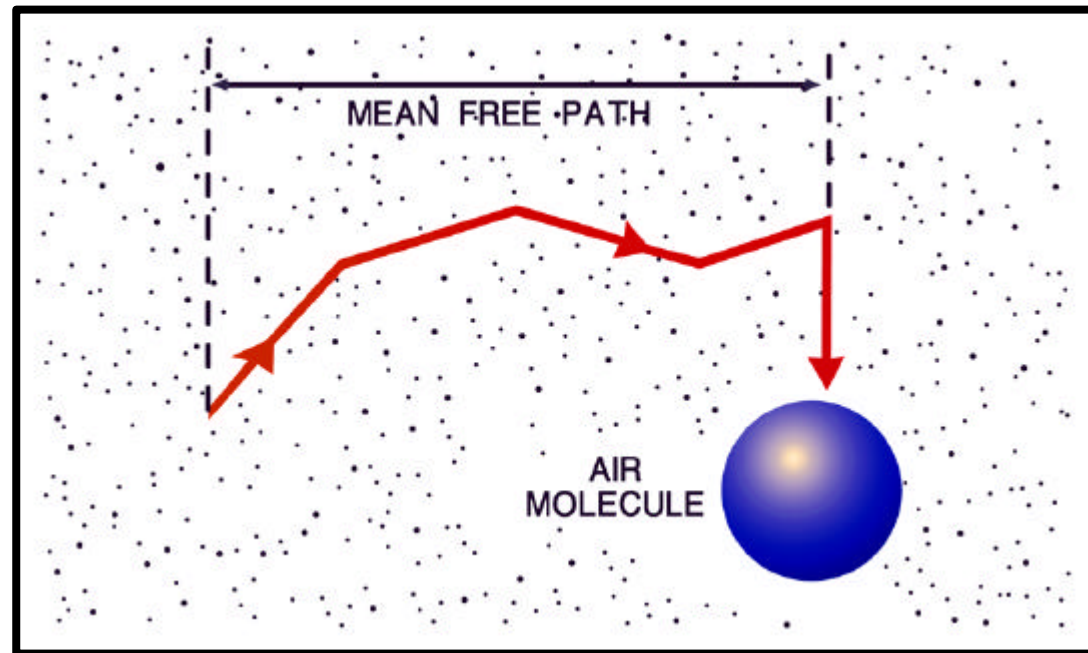
- Molecules from surrounding media bump into particles
- Momentum transferred
- Bigger particles have more inertia, harder to transport



Mean Free Path



- Average distance molecules travel before changing direction 90°



Particles In Air



- **Average of about $0.004\ \mu\text{m}$ between molecules**
- **$0.066\ \mu\text{m}$ mean free path**
- **$0.1\ \mu\text{m}$ particle 260 x molecular diameter**



Particles In Air: Stokes Law



- **Particles will experience “slip”**
 - Stokes formula describes how much particles will slip
 - Larger particles slip more than small
 - Settling velocity derived from Stokes formula



Settling Velocity in Stagnant Air

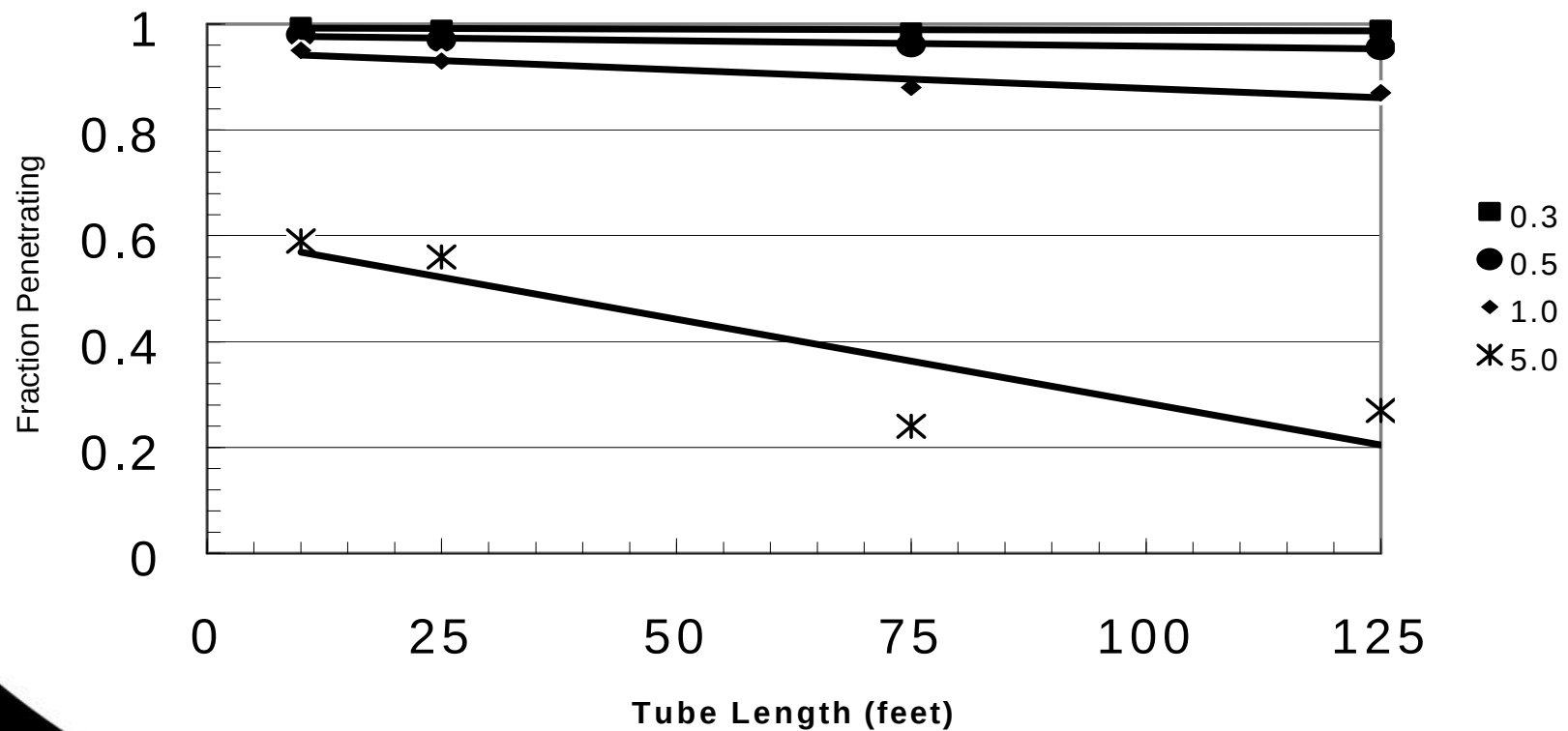


Particle Size μm	Slip Correction	Settling Velocity (cm/s)
.00037		
0.01	23.04	6.95×10^{-6}
0.1	2.866	8.65×10^{-5}
1.0	1.152	3.5×10^{-3}
10	1.015	3.06×10^{-1}
100	1.002	2.62×10^1

Particle Transport Through Tubing (laying flat)



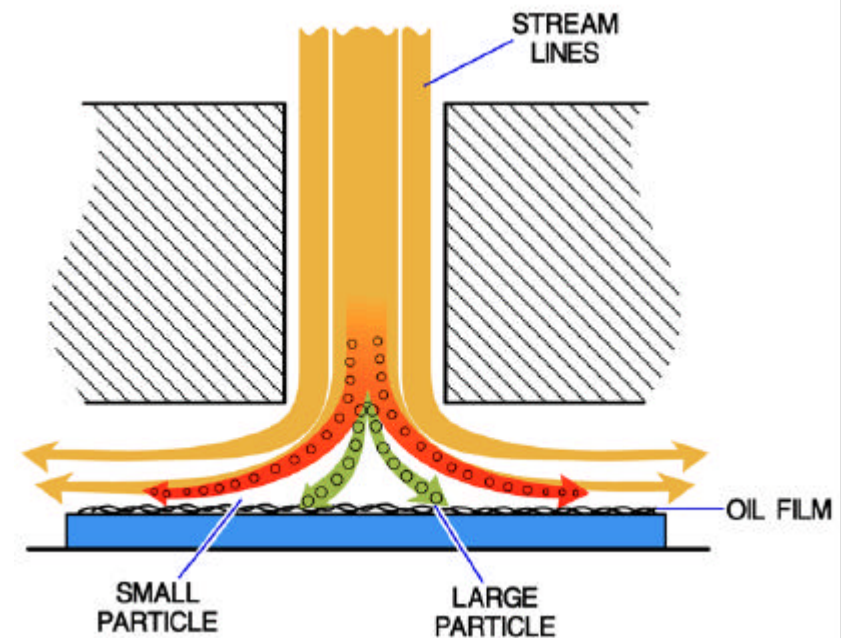
Figure 2. Particle Loss Rates in Bev-a-line XX tubing, 3/8 I.D., using PMS 3 CFM Aerosol Manifold Flow Rate



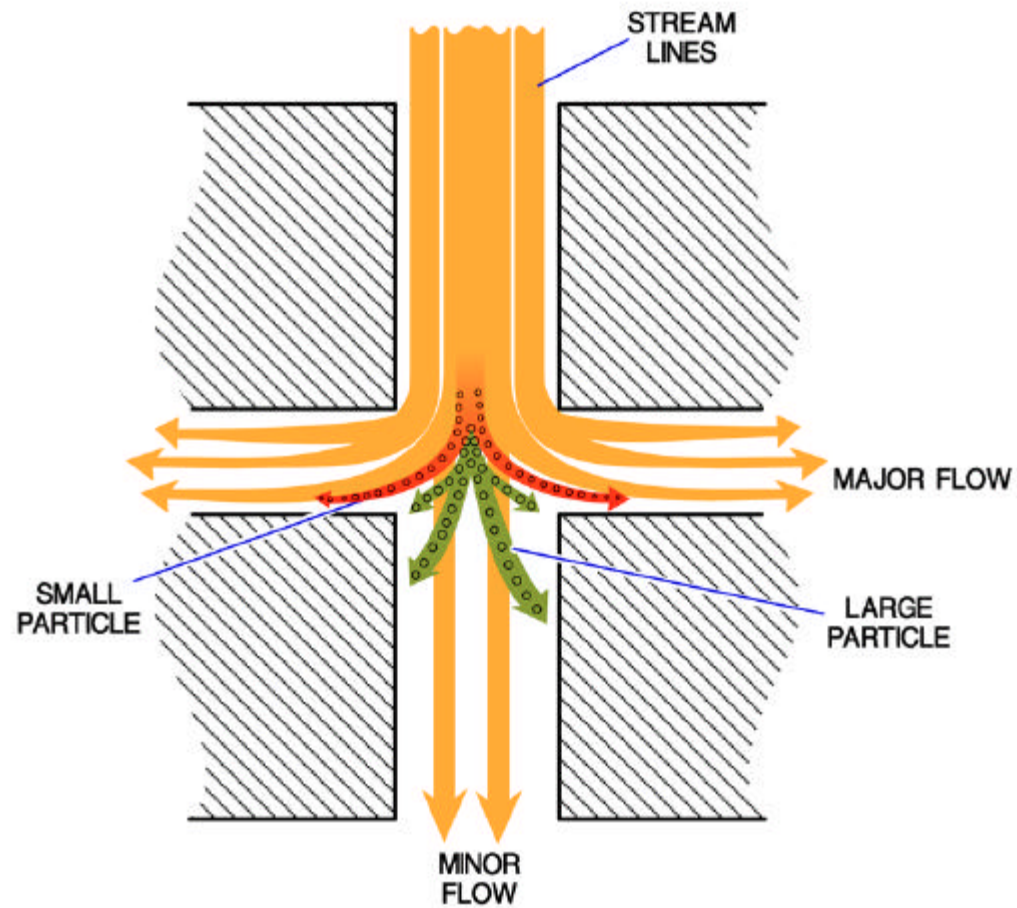
Particle Impactors



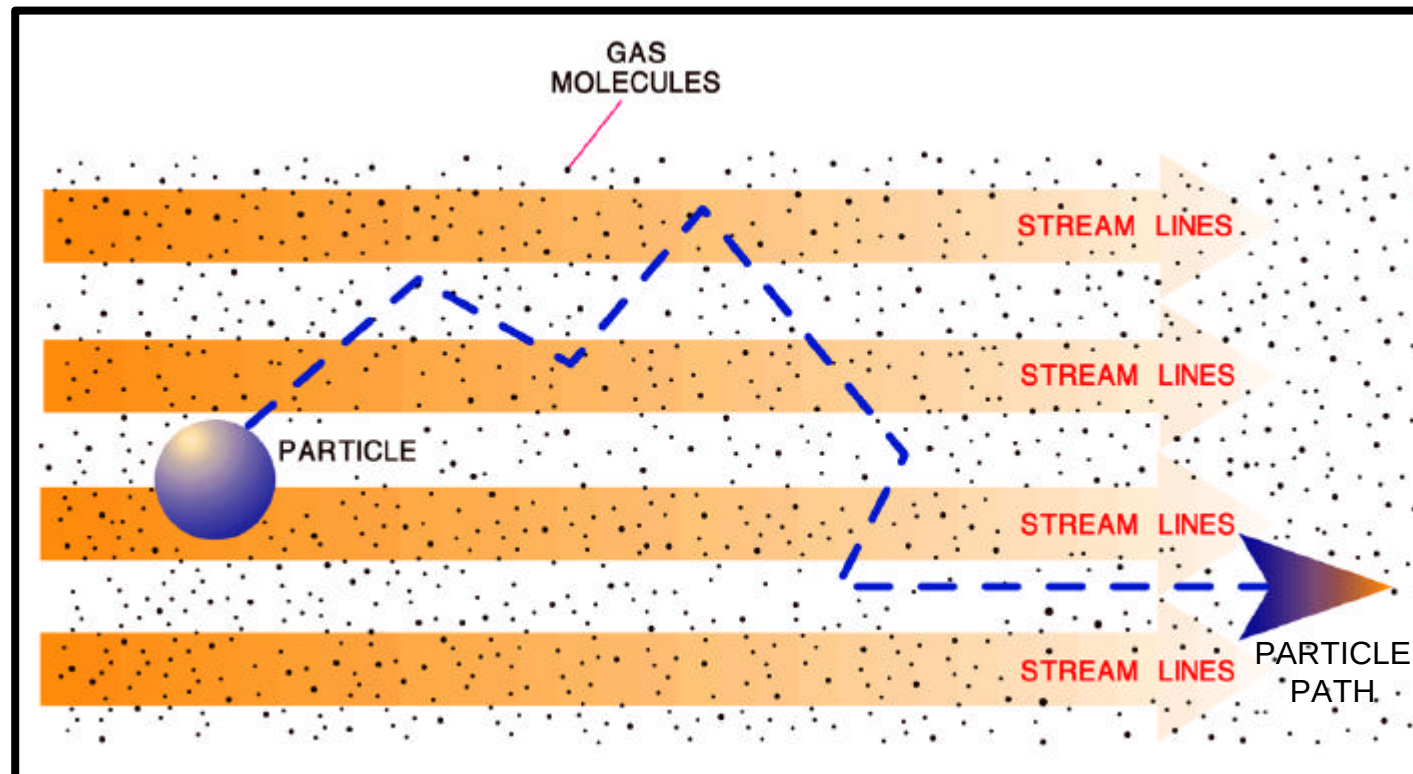
- Utilize particle inertia to capture large particles
- Small particles negotiate corner, large ones crash into wall and stick
- Can be used to sort particles by size



Virtual Impactor



Brownian Motion



Diffusion Batteries



- **Uses Brownian motion to capture small particles**
- **Made of wire screens**
- **Sort of opposite to impactor**



Particle Filters



- **Aerosol Filters**
- **Filtering mechanisms**
- **Filter performance**
- **Liquid filters**
- **Other filters**

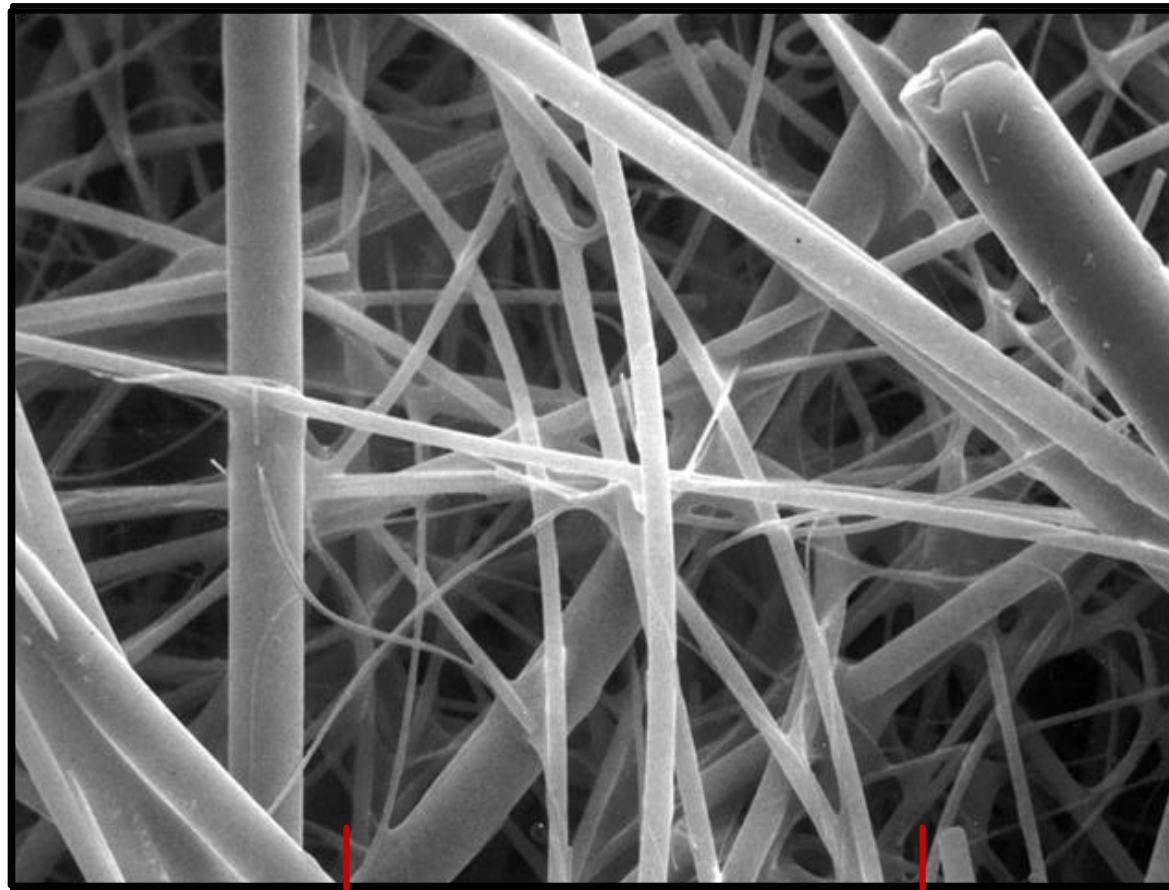
Aerosol Filters



- **Bunch of fibers interwoven together**
- **Not sieve**
- **Other types also, but much less common**
 - Sintered metal filters



Typical Filter



25 μm

Filtering Mechanisms: Sieving



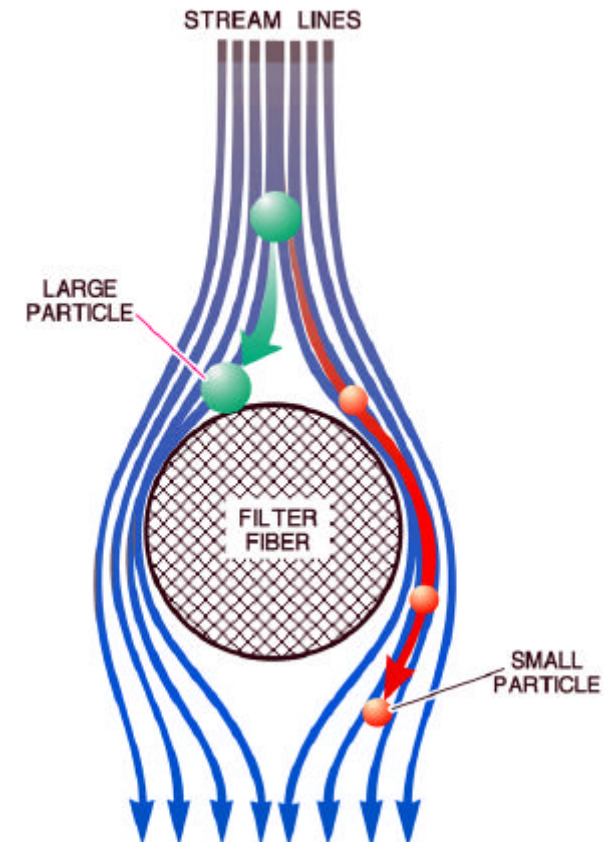
- Large particles too big to fit through pores
- Pore sizes on the order of microns



Filtering Mechanisms: Impaction

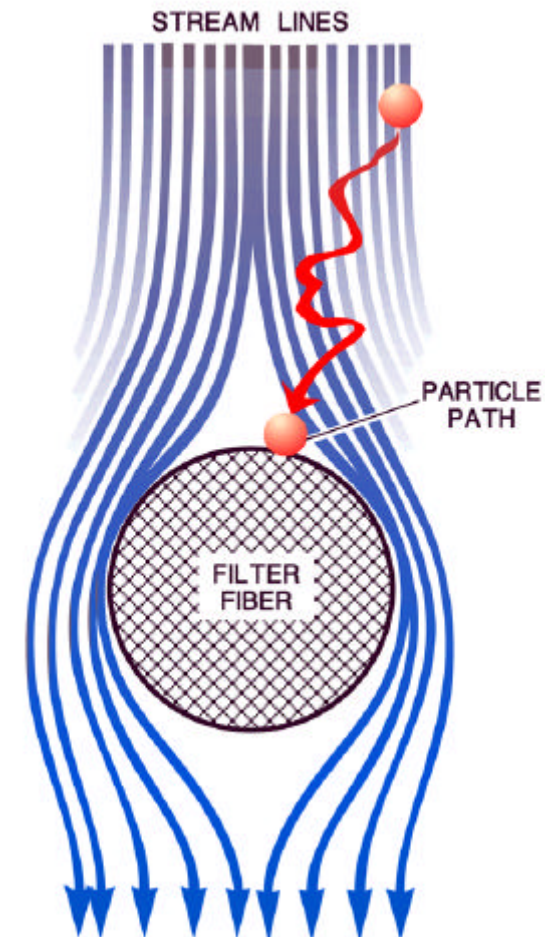


- Large particles don't follow flow lines
- Bump into fibers and stick

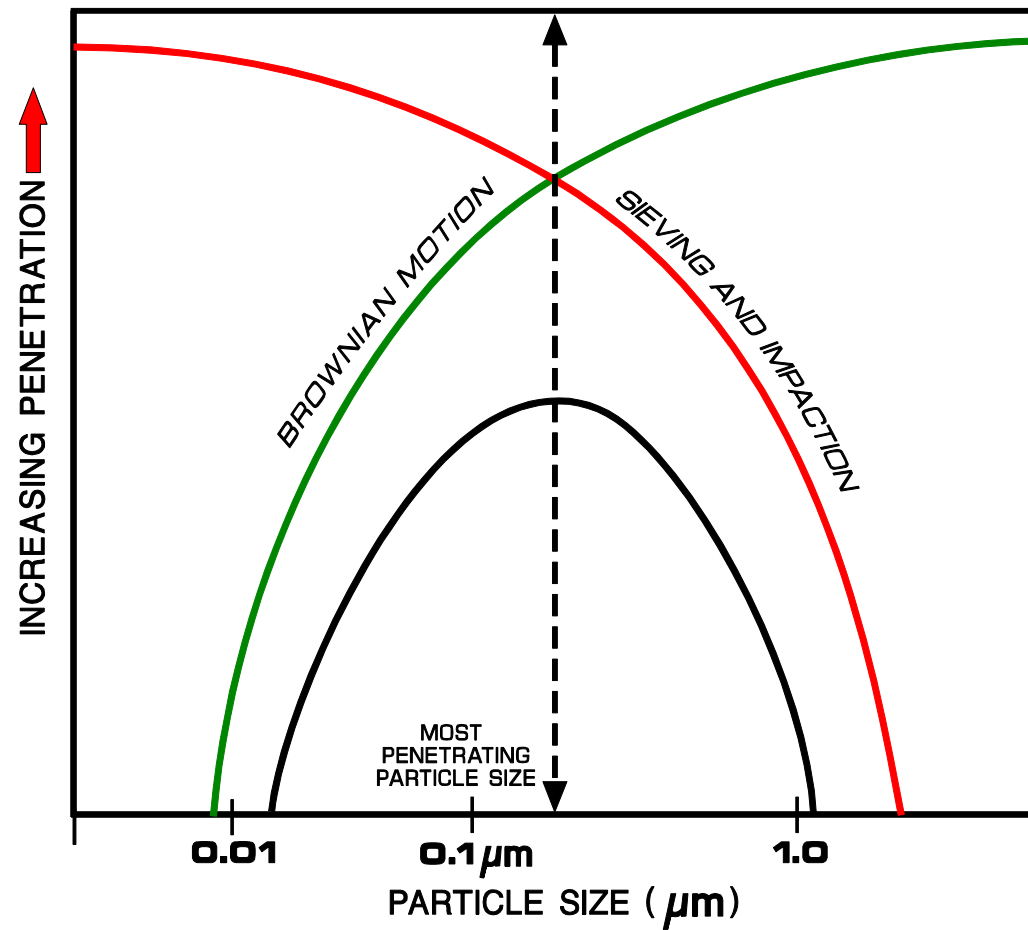


Filtering Mechanisms: Brownian Motion

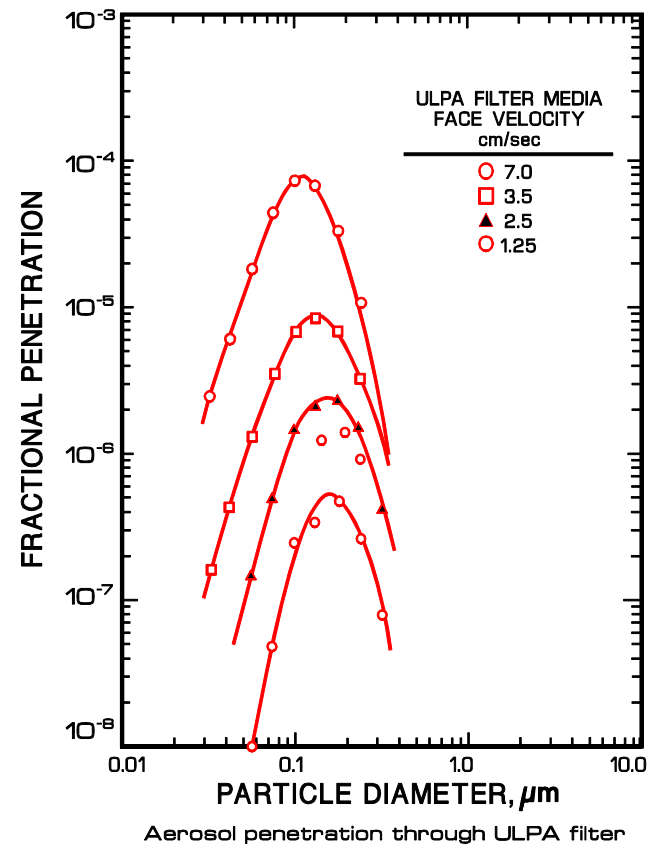
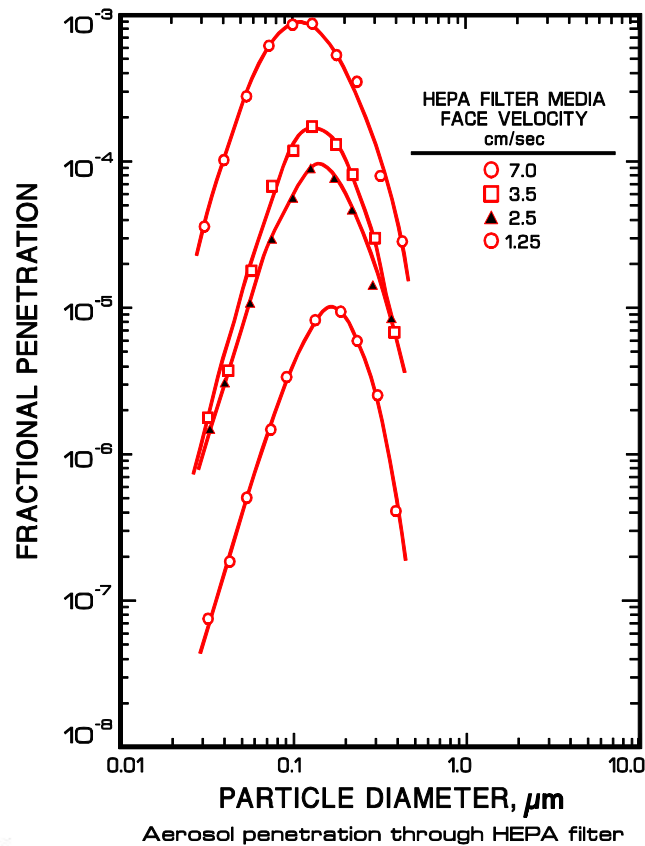
- Small particles move around across flow lines
- Chance of bumping into fiber is high as particle wanders around
- Adhesion forces retain particle



Filter Characteristics



HEPA and ULPA Filter Performance



General Filter Considerations



- **Filters become more efficient as they age**
- **Pressure drop increases as filters age**
 - Takes more power to maintain same flow rate
- **Filters more efficient at lower flow rates**
 - If flow rate too low it creates stagnant air in cleanroom
 - Optimum flow rate 60-90 ft/min (face velocity)
- **Pleated to increase surface area**
- **Vibration, pressure changes can shake particles loose**



Liquid Filters

- **Sieving now primary filtering mechanism**
 - Need small pore sizes
 - Larger pressure drop
- **Fiber filters**
- **Other types**
 - Membrane filters (Gore-Tex®)
 - Ceramic
 - Earthen bed
- **Chemistry can affect filter performance**
 - Hydrophillic vs. hydrophobic, etc



Liquid Filters

- **More efficient with age**
- **Larger pressure drop**
 - Can lead to filter breakthrough
 - Pressure drop becomes too large, creates hole in filter
- **Bacteria growth**
 - Require filter change or peroxide purge



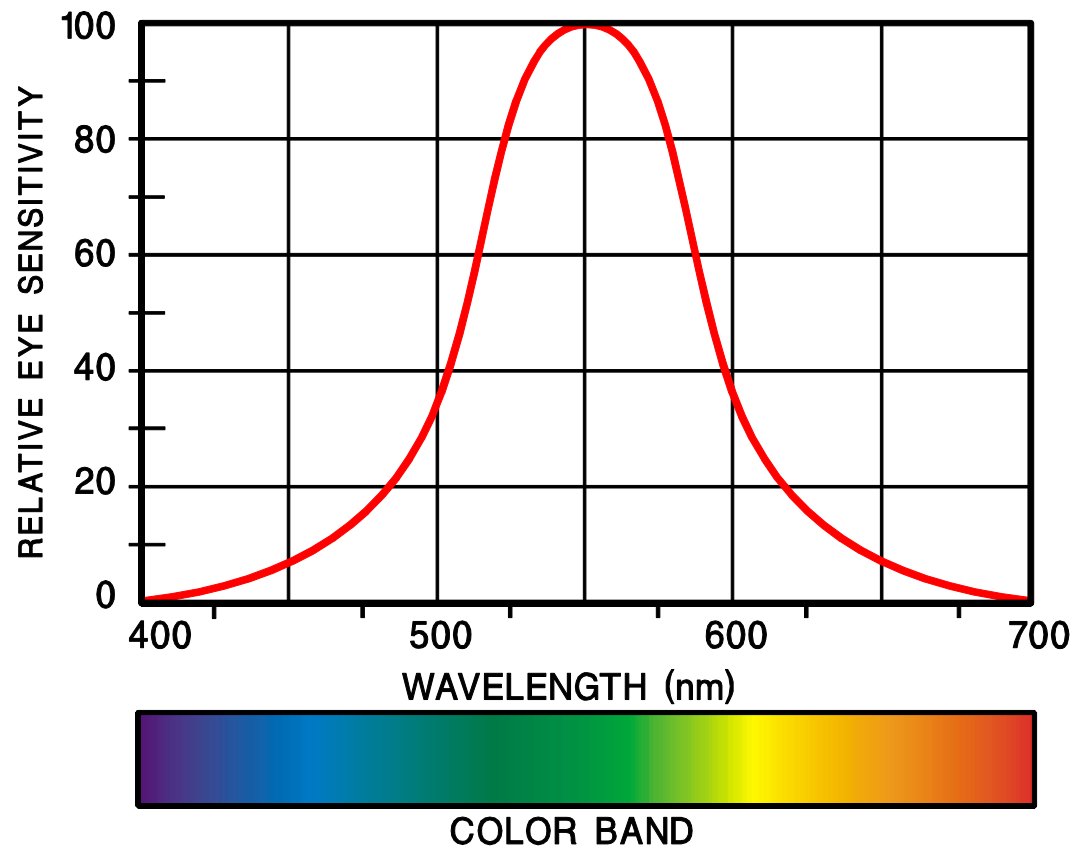
Light Scattering by Particles



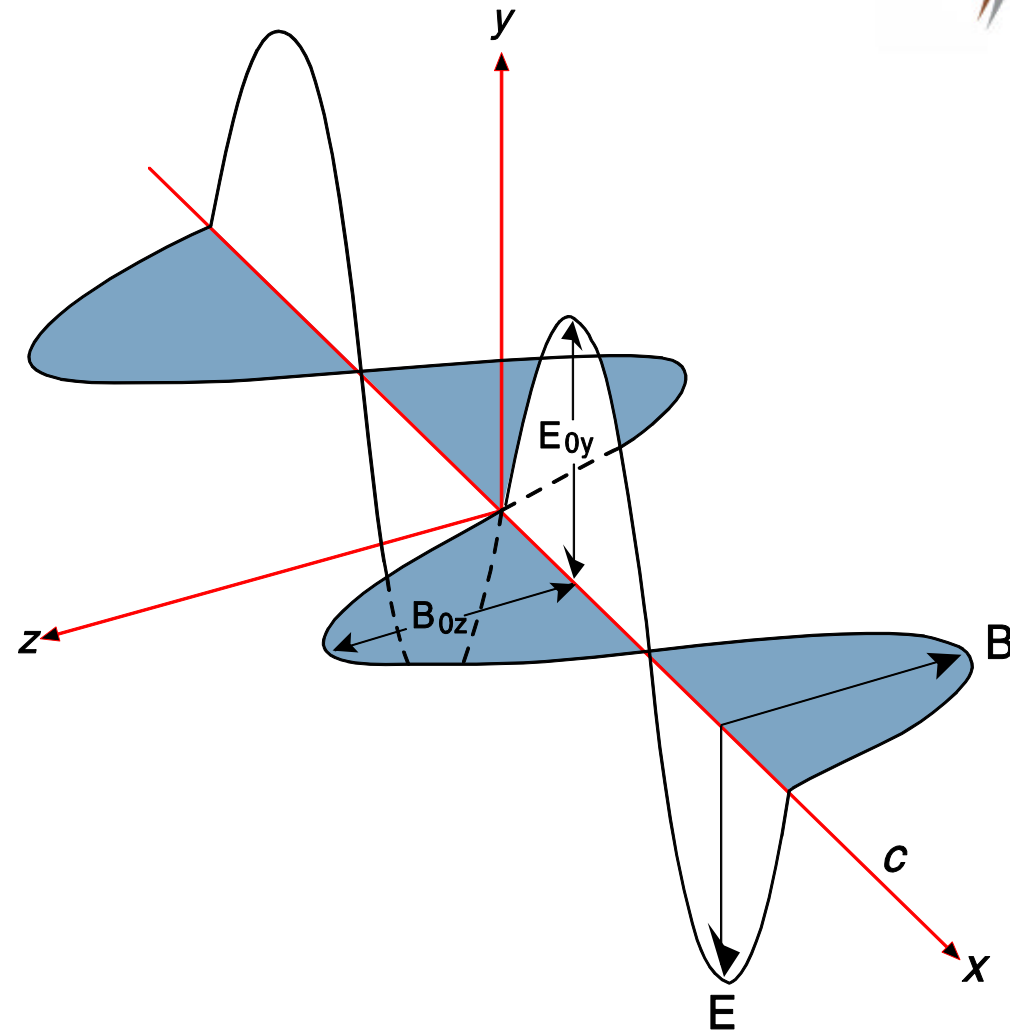
- **Light basics**
- **Laser basics**
- **Light - particle interactions**
- **Basic Mie scattering curve**
- **Basic scattering relationships**



Light Spectrum



Polarization

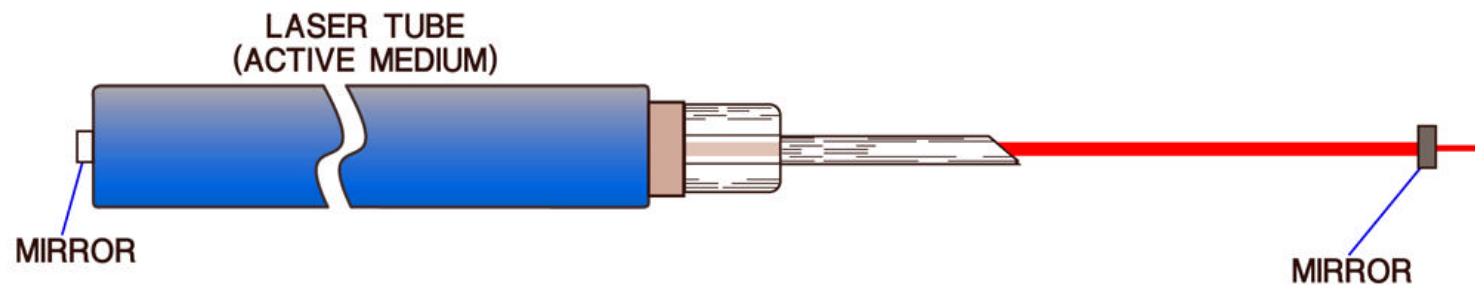




Laser Basics

- **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
- **Stimulated emission: Photon interacts with excited atom/molecule and 2 photons are created with the same phase, wavelength, and direction as original photon**
- **Lasers comprised of active medium and two mirrors**

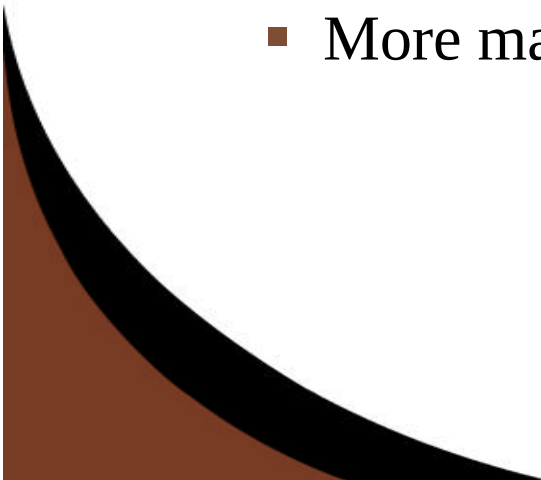
Laser



Laser Characteristics



- **High Brightness - Focus all of the power to a small spot**
- **Optical Cavities**
 - Store power for better sensitivity
 - Contamination of optics reduces cavity Q (ability of the cavity to store power)
 - More maintenance



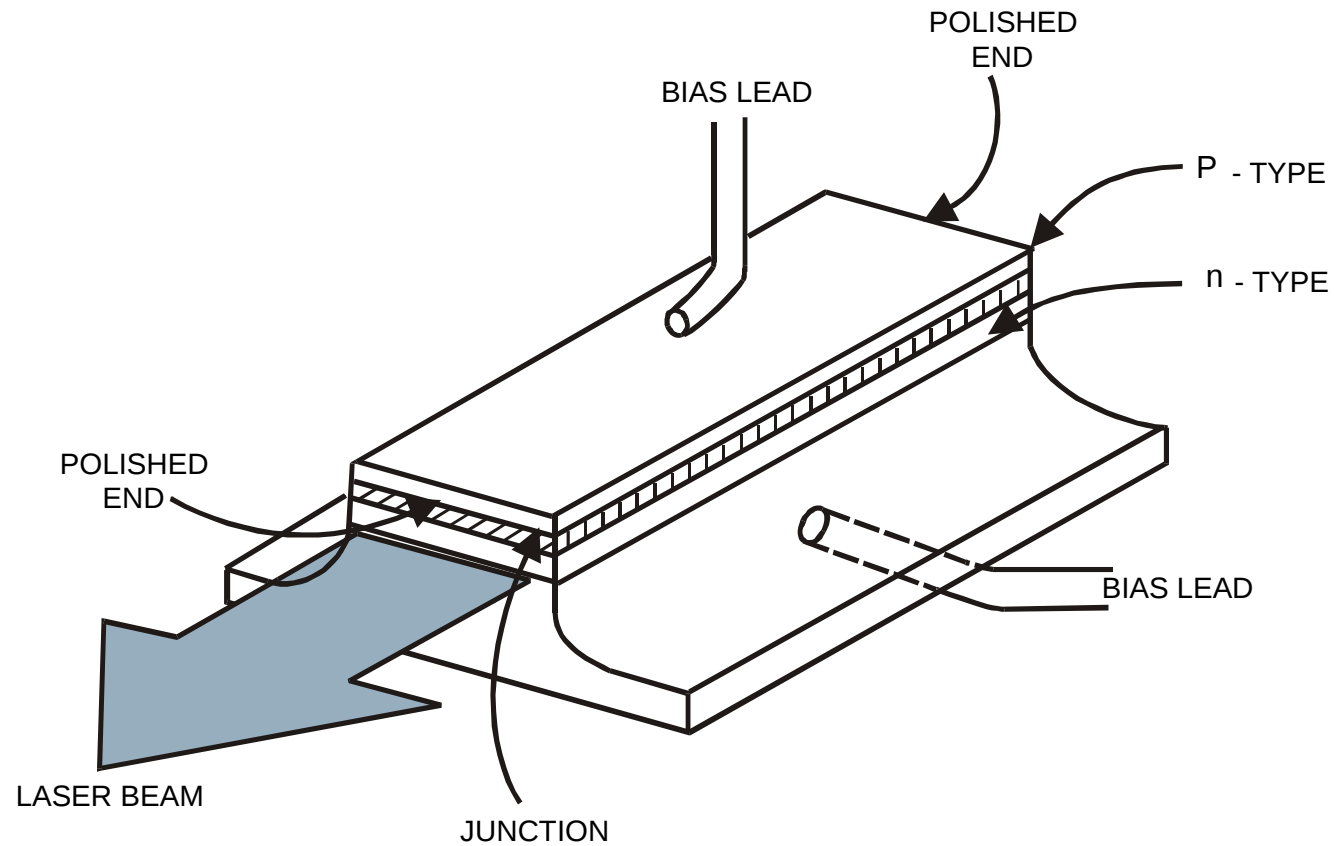
Types of Lasers Used for Particle Counters



■ **Laser Diodes**

- Small
- Inexpensive
- Reliable
- Sensitive to high temperature
- Should be de-rated
- No cavity possible, so lower sensitivity instruments
- 5-50 mW typical power outputs
- Sensitive to ESD

Diode Laser





Lasers, cont.

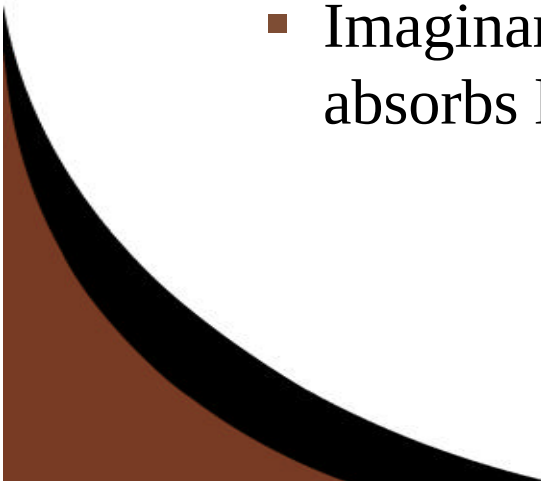
■ Helium Neon

- Standard laser 5 mW
- Optical cavities
- Active cavity, 100 W
- Passive cavity
 - Relatively high power, 5W
 - Less maintenance than active cavity
- **Laser life similar to diode, but more maintenance**

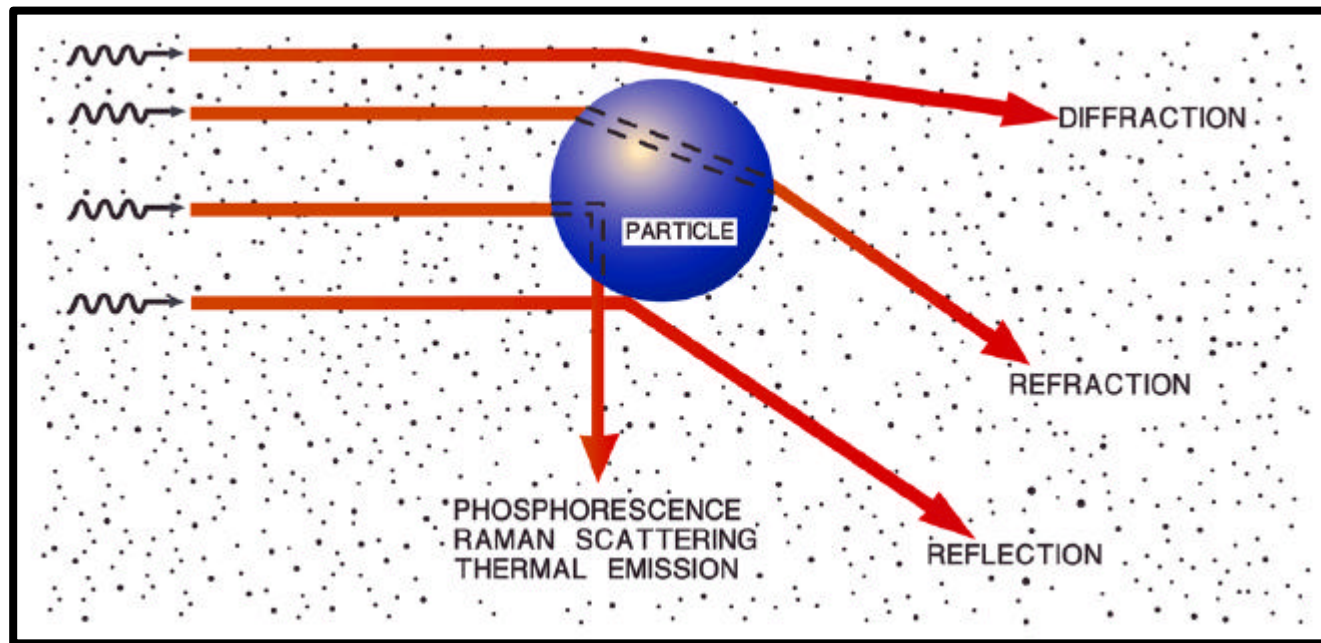
Light Scattering



- **Scattering takes place because of differences in the index of refraction**
- **Index of refraction**
 - Complex number
 - Real part describes how much light slows down
 - Imaginary part describes how strongly the material absorbs light



Scattering Phenomenon



Scattering Assumptions for Particle Counters

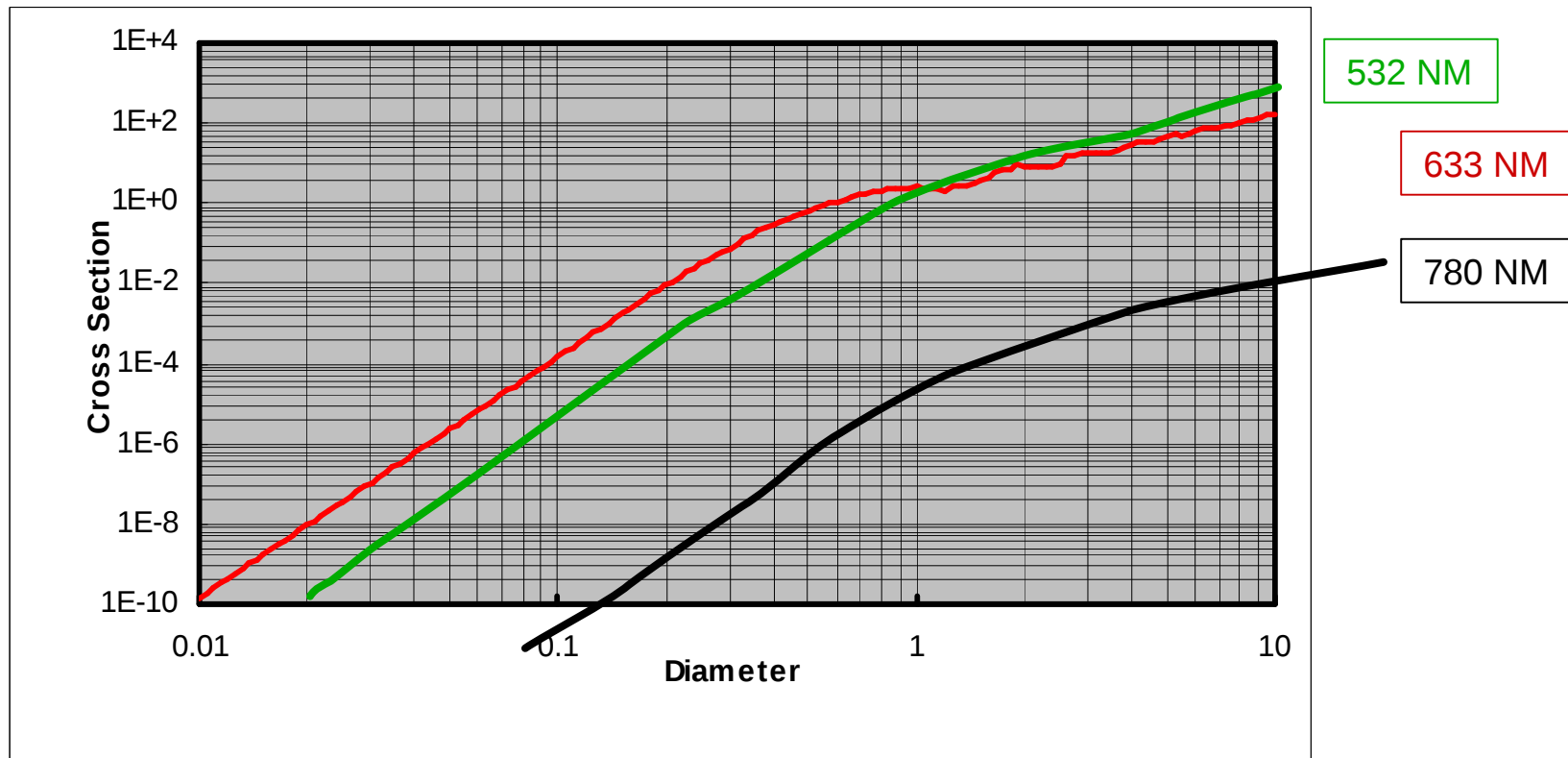


- **All particles are spherical**
 - Real particles sized by scattering equivalent to polystyrene latex spheres

- **All particles have an index of refraction of $1.59 + 0\text{ im}$**



Basic Scattering Curve



Scattering Relationships



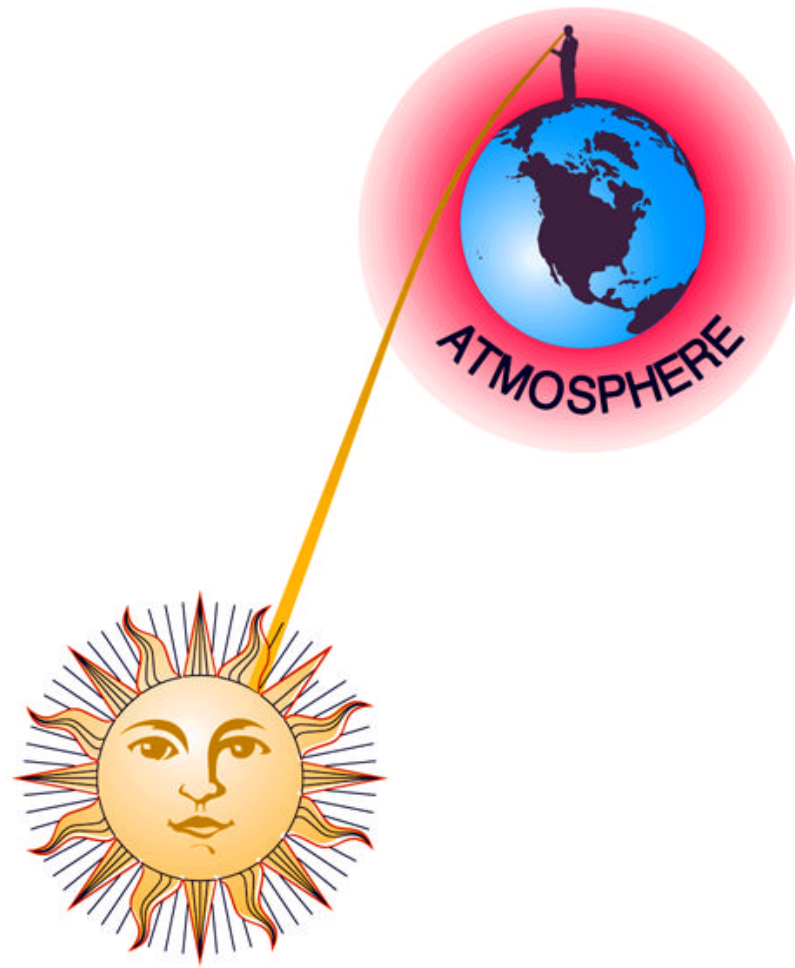
- **Scattering increases as $1/l^4$**
 - For relatively small particles, large particles have no wavelength dependence
- **At sizes below about $0.2\ \mu\text{m}$ scattering increases as $1/(\text{diameter})^6$ (Rayleigh scattering)**
- **At sizes above $0.5\ \mu\text{m}$ scattering increases around $1/(\text{diameter})^2$ (MIE scattering)**
- **In air at 633 nm 1 part per million scattered per meter**

Why Is The Sky Blue?

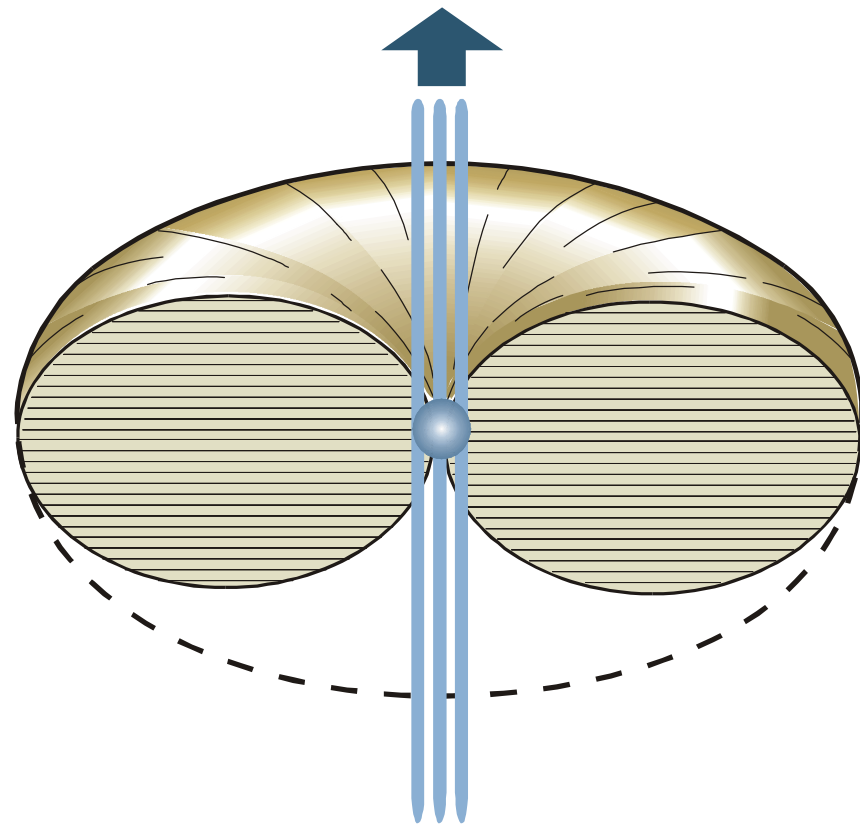
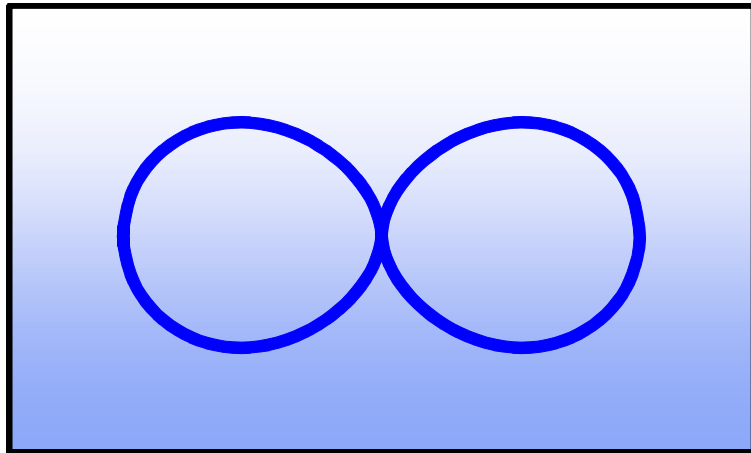


- Shorter wavelengths scatter more efficiently
- Blue light - 450 nm
- Green light - 550 nm
- Red light - 650 nm

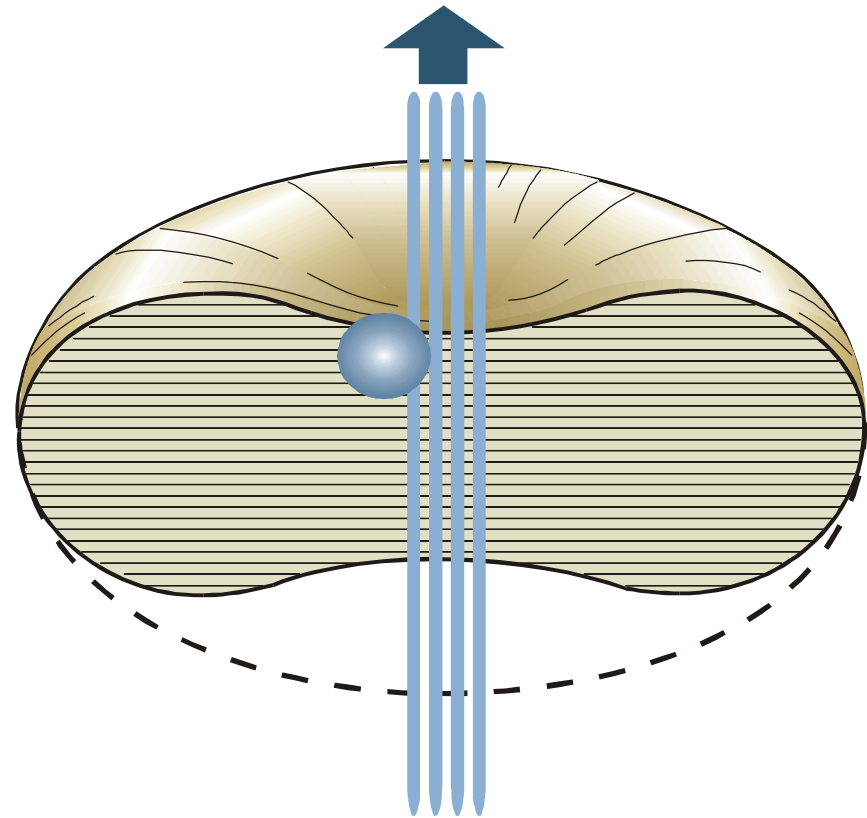
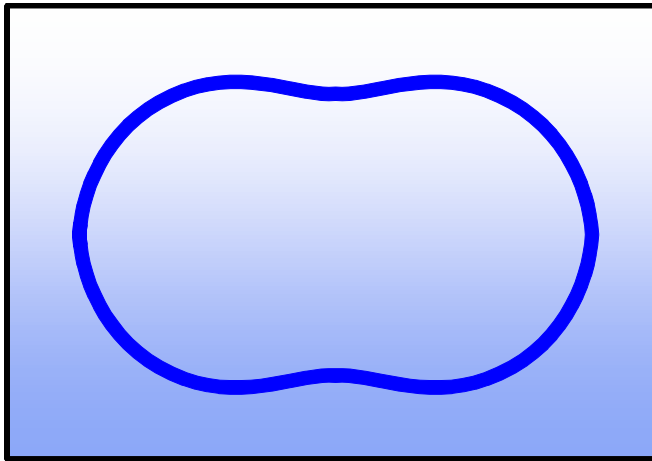
Why is the Sunset Red?



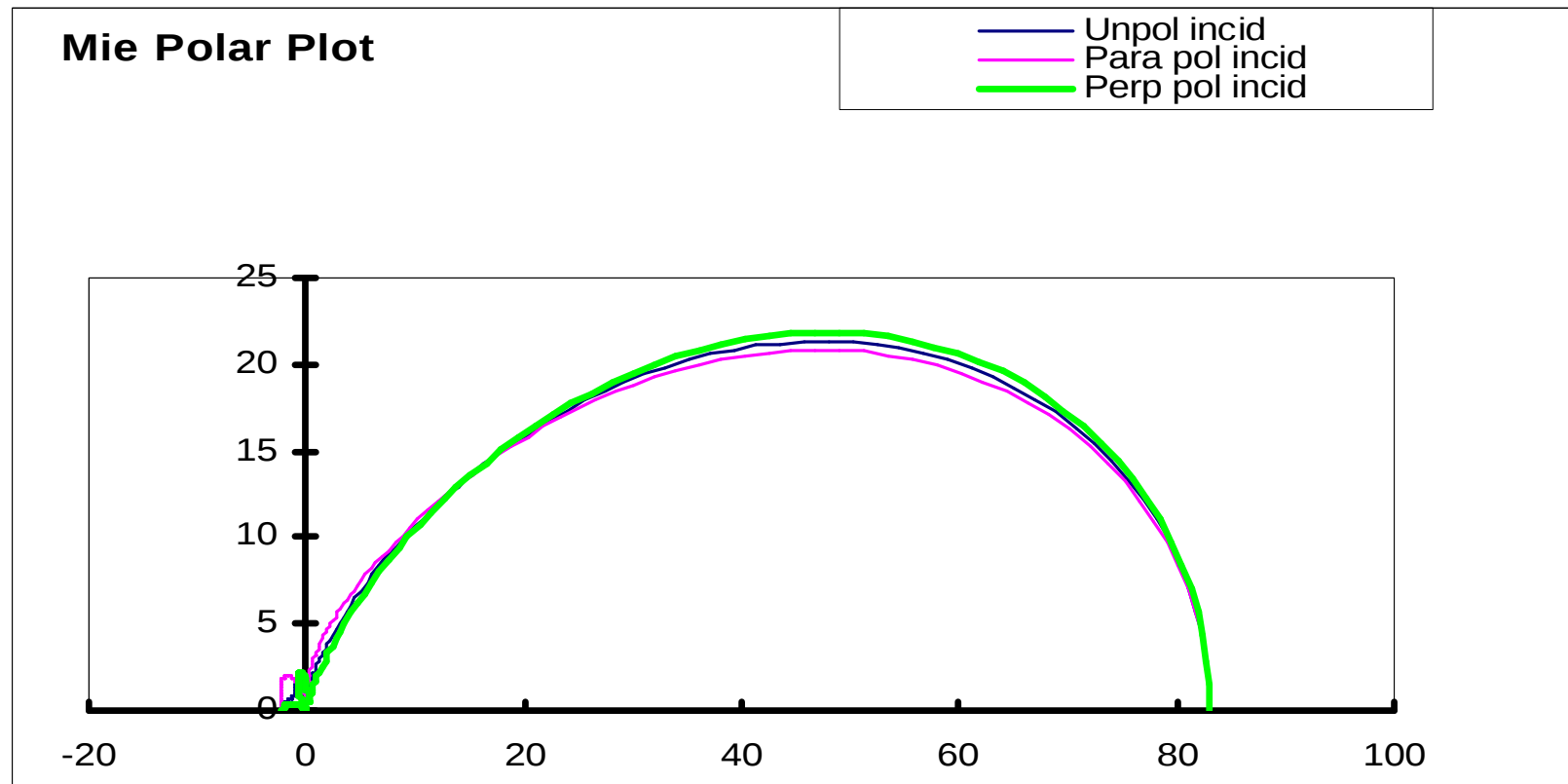
Spatial Distribution of Scattering From Polarized Light



Distribution From Non-polarized Light



Large Particle

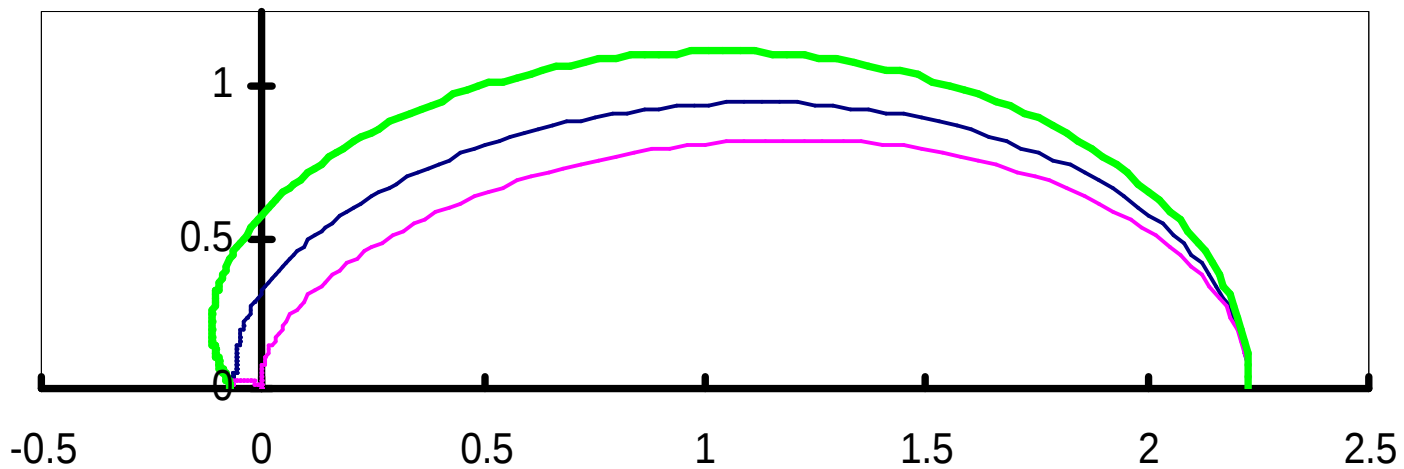


0.3 μm Particle



Mie Polar Plot

— Unpol incid
— Para pol incid
— Perp pol incid

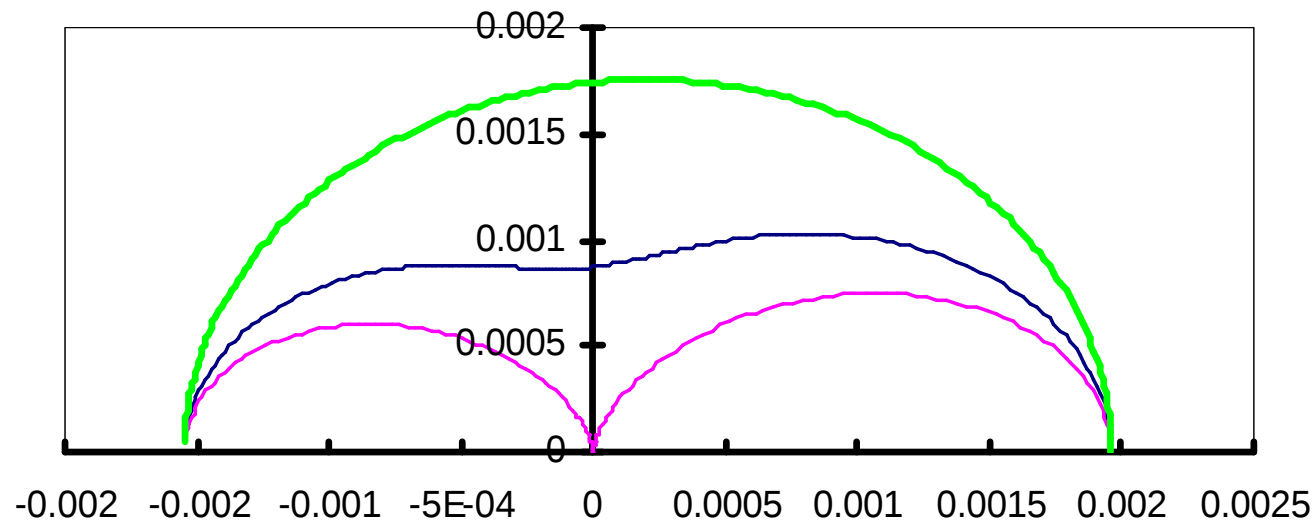


0.1 μm Particle

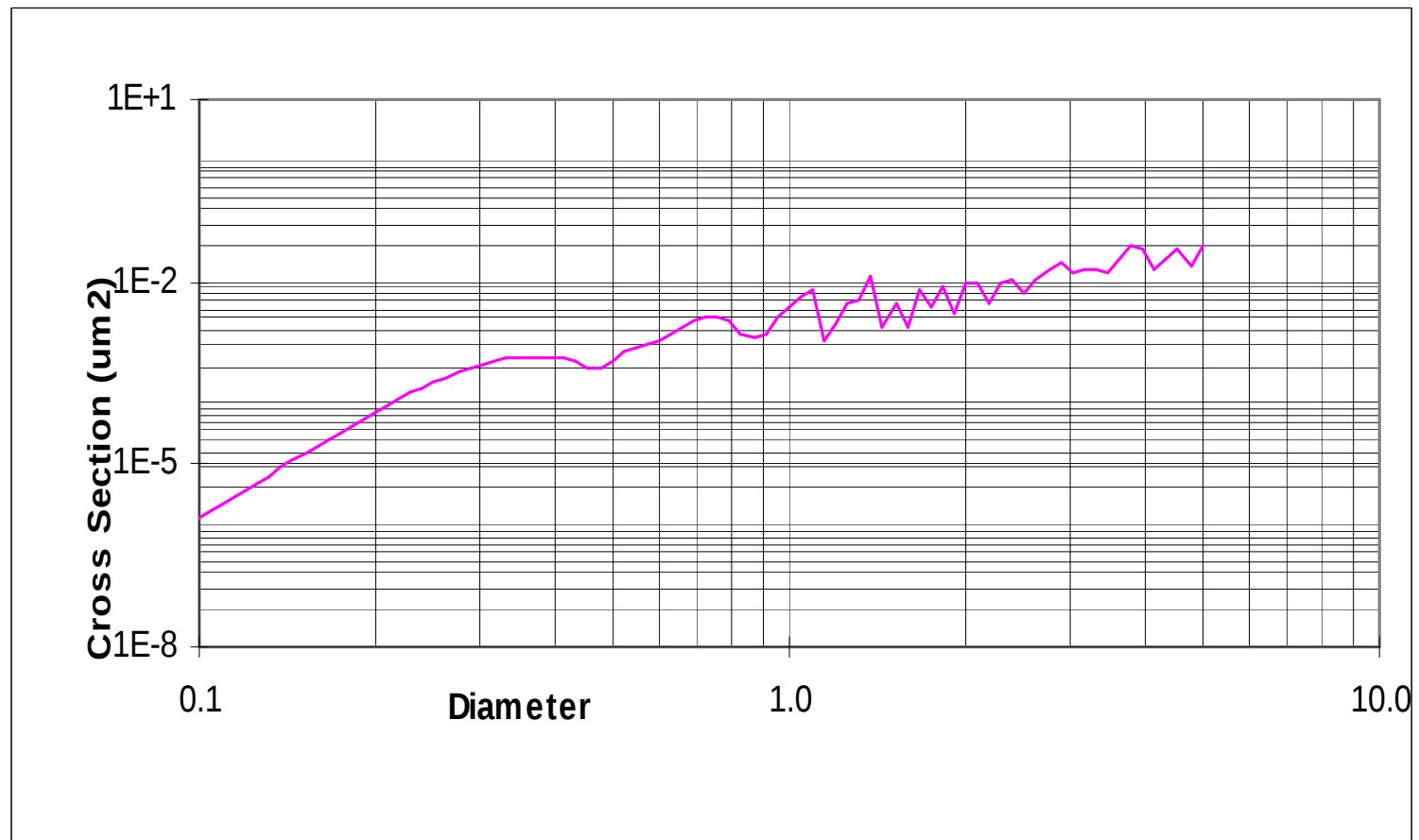


Mie Polar Plot

— Unpol incid
— Para pol incid
— Perp pol incid



Small Collection Angle



Limits On Detecting Particles With Light Scattering



- **Scattering from fluid background, or molecular scattering, becomes limiting noise**
 - Random “shot noise” on DC background
- **Break sample volume into small parts and look at these small sections individually**
 - Array detectors, parallel processing
 - PMS patent
- **Currently limit is 0.05 mm in both air and water**

Summary



- **Scattering is created from index of refraction differences**
- **Particle counters assume all particles are spherical and made of rubber**
 - Provide equivalent size
- **Different particle counters can give different answers depending on optical geometry**

Summary cont.



- **Most particles in cleanrooms are from people or people related activities**
- **A properly operating state-of-the art cleanroom has effectively no particles**
- **Particles below 1 micron settle very slowly**
 - Carried effectively by air at atmospheric pressure
 - Small particles can be measured through long lengths of tubing

Summary cont.



- **Aerosol filters are least effective between 0.1 to 0.2 μ m**
 - Filter by combination of sieving large particles and capturing small particles through Brownian motion
- **Liquid filters are effectively sieves**



Questions?



Questions?

Questions?

Questions?

