Particle and Aerosol Technology

Professor Mansoo Choi

1. S.K. Friedlander, "Smoke, Dust and Haze-Fundamentals of Aerosol Dynamics" Wiley, 2nd Ed., 2000.

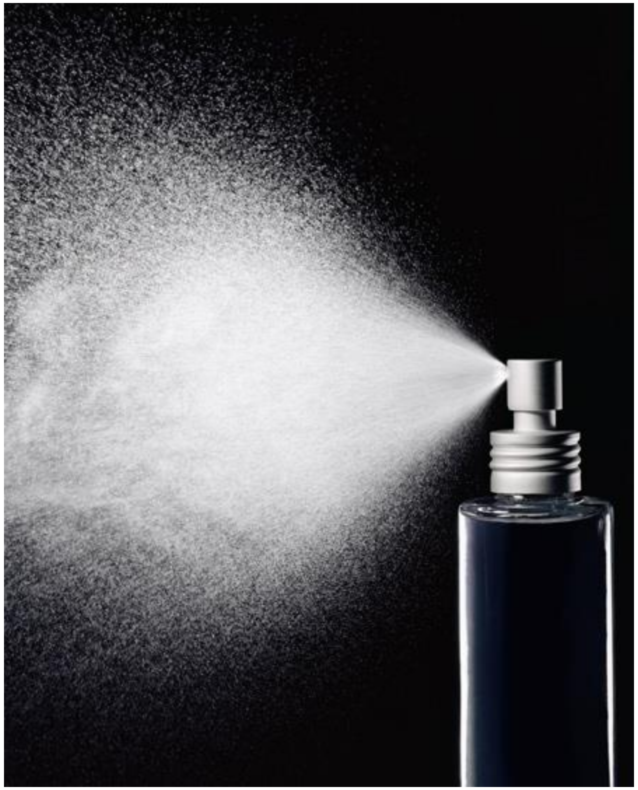
2. W.C. Hinds, " Aerosol Technology-Properties, Behavior, and Measurement of Airborne Particles", Wiley, 2nd Ed., 1999

3. P.C. Reist, "Aerosol Science & Technology", 2nd Ed., McGraw-Hill, 1993

4. R.C. Flagan, J. Seinfeld, " Fundamentals of Air Pollution Engineering", Prentice Hall, 1988

Related Journals : Journal of Aerosol Science, Aerosol Science and Technology

Aerosols?



Definition: solid or liquid particles in gas

: Aerosols are stable suspensions of small particles in gases. They are formed by the conversion of gases to particles or by the disintegration of liquid or solids. They may also result from the resuspension of powdered materials or the breakup of agglomerates. Smoke, dust, haze, fume, mist, fog, and soot are terms that refer to “aerosols”.

Fine Dust (미세먼지)

1. Aerosols are ubiquitous among us throughout our ambience and are important to our health since airborne particulate matter is a complex mixture of many different chemical compositions (maybe containing carcinogenic materials) : air quality, yellow dust, vehicle emission, indoor aerosols, bioaerosols, etc.

2. In relation to nanotechnology, nanoparticles that exist in gases are also called as aerosols. Nanoparticle synthesis (controlled) and its applications to nanodevices belong to aerosol science and technology.

3. Control technology about aerosols are very important to versatile kinds of industries including semiconductor industry, filtration industries, material synthesis industries, pharmaceutical industries, etc.

--→ All aerosol behavior in these different fields is dependent on particle characteristics such as particle size, morphology, composition, concentration.

-→ Aerosol dynamics can describe the evolution of particle characteristics.

Aerosol definition

Aerosol characterization & Instrumentation

Aerosol behavior : diffusion, electric property, interaction with fluids, optical property, deposition

Aerosol dynamics ; coagulation, evaporation, condensation, convection → evolution of particle characteristics

Aerosol technology : filtration, nanoparticle synthesis and applications

Aerosols : Aerodisperse system

Definition

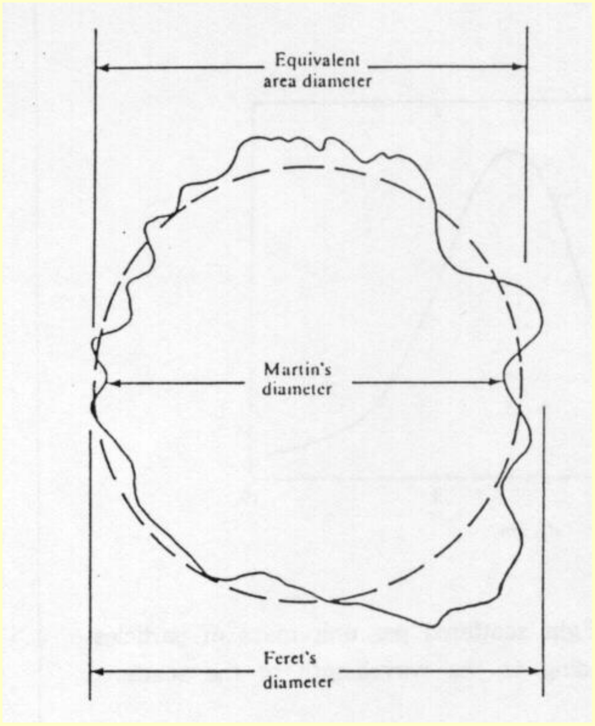
- A suspension of solid or liquid particle in a gas
- Particle size ranges from about 0.001 ㎛ to more than 100 ㎛

Classification of particles by their size

- Fine particle~ 10 ㎛ (10,000nm) > 1 ㎛
- Ultra-fine particle ≤ 0.1 ㎛ (100nm)

Shape of particle

- Normally non-spherical shape
- For theoretical analysis equivalent diameter is used.
- Equivalent diameter depends on particle behaviors and properties.



Dispersed System

	CONTINUOUS PHASE	DISPERSED PHASE
AEROSOL	GAS	SOLID OR LIQUID
HYDROSOL	LIQUID	SOLID OR LIQUID
FOAM	SOLID OR LIQUID	GAS

Disperse systems with a gas-phase medium and a solid or liquid disperse phase are called aerosols or aerodisperse systems.

Aerosols

Aerosols consisting of solid or liquid particles suspended in a gas not only play a very large part in our nature and life, but also have been utilized in important industry applications including information technology, environmental technology, nanotechnology, biotechnology, etc.

Aerosol science and technology can be classified as one of the fusion technology having interdisciplinary nature.

1.Nature

: Clouds, Fog, Sand Storms, Yellow sands, Pollens

Clouds are the collection of small water droplets in sky where water vapor condensation occurs.

Sand storms and yellow sands are governed by erosion, transport and deposition of earth surface or resuspension of sands or small solid particles attached on earth surface by wind.

Radioactive aerosols : natural (earth radon) or artificial (Xe ; 제논 , 크세논)

Cross-pollination of grasses and many trees is affected by the pollen being scattered as an aerosol by the wind. Considerable numbers of seeds and spores are spread in a similar manner. Many micro-organisms preserve their germinating power over long periods while airborne. The aerial microflora comprise a large assortment of fungi and bacteria (even virus) which have significance in medicine and in the fermentation industries.

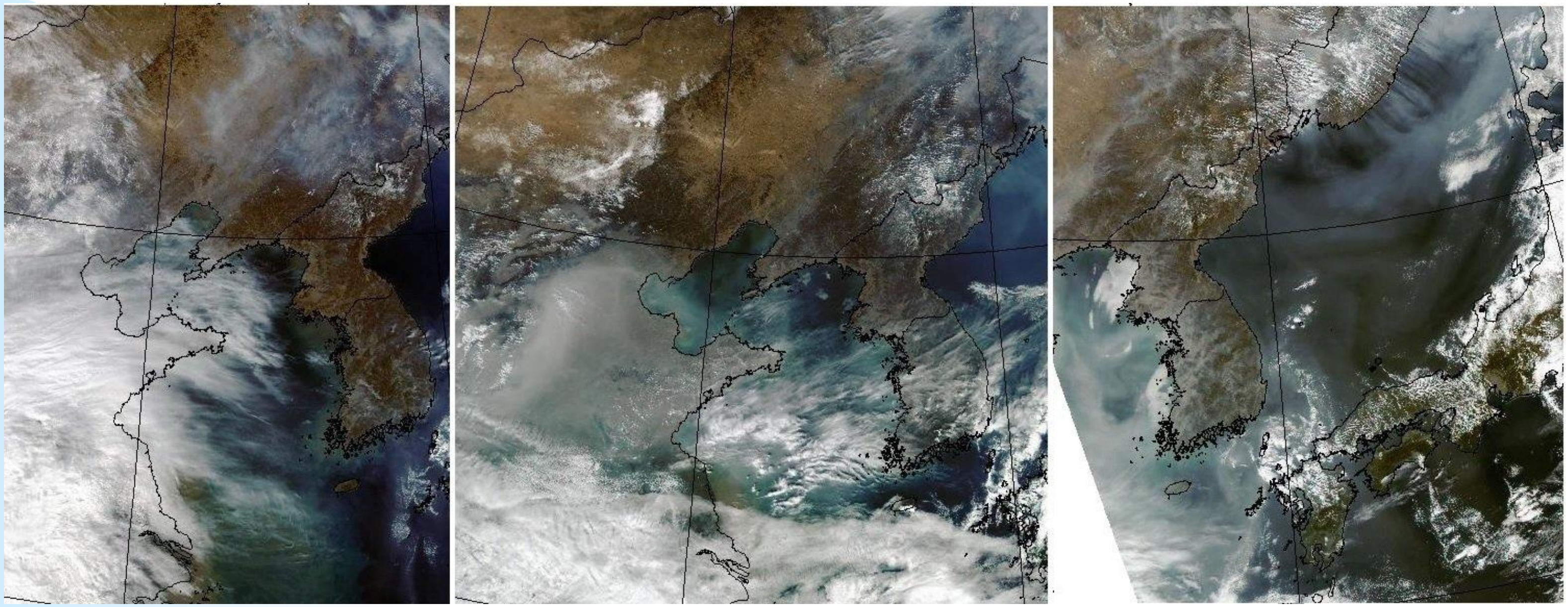
Example: avian influenza, (MERS: Middle East respiratory syndrome coronavirus)

Fine dust problem : dust generation, dust collectors, dust transportation

: Studies on generation, transportation, and deposition of aerosols in atmosphere are main topics for ATMOSPHERIC AEROSOL field.

Origin of Yellow sands: Gobi desert

고비 사막(몽골어: Говь, 중국어: 戈壁, 병음: gē bì)은 몽골과 중국에 걸쳐 있는 중앙아시아의 사막이다. "고비"는 몽골어로 "거친 땅"이라는 뜻이다. 북쪽은 알타이 산맥과 스텝 지대, 남쪽은 티베트 고원, 동쪽은 *화북평원*으로 둘러쌓여 있다. 고비 사막의 모래가 날리는 황사는 편서풍을 타고 한반도와 일본을 건너 하와이까지 가기도 한다.



미 항공우주국 테라/아쿠아 위성 사진. 왼쪽부터 2월 26일, 2월 28일, 3월 1일 사진이다. 26일 한반도 상공은 중국과 달리 맑았지만, 28일부터 중국 오염물질이 들어오면서 1일에는 서해와 한반도 서쪽이 스모그로 뒤덮여 있다. [사진 기상청 홈페이지]

[출처: 중앙일보] 2019년 3월9일

2. Life

: many infectious diseases including influenza, whooping cough(백일해), various lung infections and tuberculosis, are undoubtedly spread through the air.

Virus aerosols are responsible for measles(홍역) and mumps(유행성이하선염). Aerosol form of Bacillus Anthracis(탄저균)was used as a kind of bioweapon by terrorists.

Mers-(Middle East Respiratory Syndrome) CoV, SARS(severe acute respiratory syndrome)

Dusts containing silica(SiO_2) which are formed during drilling and mechanical grinding of siliceous rock, are very injurious to the lungs, for example, silicosis (규폐증) is one of the most dangerous and widespread occupational diseases. Asbestos is kind of fiber type mineral particles that may be spread in air and may cause lung cancer.

Radiactive aerosols formed in the atomic bomb explosion or possible accident represent an enormous danger.

On the other hand, some medical preparations are particularly effective when administered by inhalation as aerosols: drug delivery

:Studies on generation, transport, sampling, detection and filtering of these biomolecular aerosols are the topic for "BIOAEROSOL field"

3. Technology

Traditional :

The winnowing of grains consists of suspending the mixture of grain and chaff as an aerosol and then separating the two constituents with an air stream : Separation technique for aerosols

Diesel fuel spray makes aerosol form and the size of droplets is one of the important parameter that influences the combustion process. The combustion of pulverized solid fuel.

Pesticide is applied to grain field as an aerosol form.

Pest and mosquitoes control have been done by aerosol spray. Military operation was also done using aerosol form such as smoke screen bomb(연막탄).

Relatively new: optical fiber fabrication, clean room for semi-conductor industry, powder metallurgy, filtering of air pollutants such as electrostatic precipitators, air purifier

Emerging: nanoparticle generation and deposition, drug delivery, aerosol nanoarchitecturing for fabricating nanodevices such as gas sensors, solar devices and others

Current Applications

Core Technology

Fine Particle Control

ET

Hygiene Technology

- Toxic Pollutant Evaluation
- Respiratory Disease Diagnosis
- Drug Delivery Technology
- Indoor Air Quality

Air Pollution Control

- ESP, Cyclone, Filter
- SO_x/NO_x Removal Systems
- Air Pollution Modeling

BT

Bio Technology

- Bio-Aerosol Sampling
- Antibiotic Particle Synthesis

NT

Material Synthesis

- New Material Development
- Ceramic Powder
- Catalytic Materials
- Nano-energy devices

IT

Semiconductor Related

- Cleanroom
- Thin Film Synthesis
- Optical Fiber Material

Energy

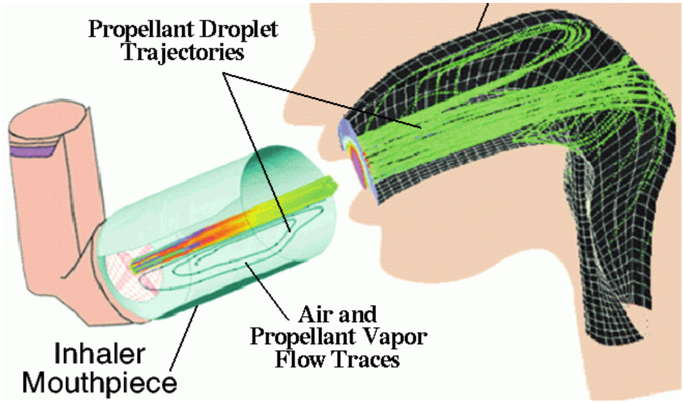
High-Efficiency Energy System

- High-Efficiency Combustion
- Energy Apparatus

Environmental Technology

Health & Hygiene Technology

- Toxic Pollutant Evaluation
- Respiratory Disease Diagnosis
- Drug Delivery Technology
- Indoor Air Quality



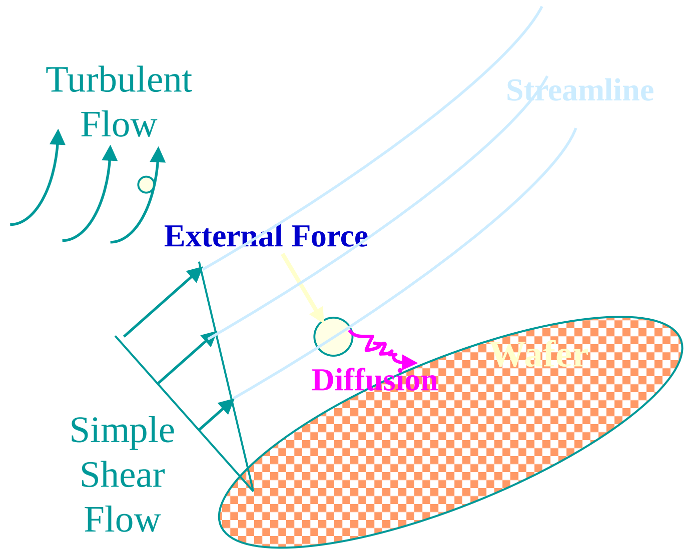
Air pollution Control

- ESP, Cyclone, Filter
- SO_x/NO_x Removal Systems
- Air Pollution Monitoring
- High Efficiency/Low Emission Combustion

IT & Energy Technology

Semiconductor Related

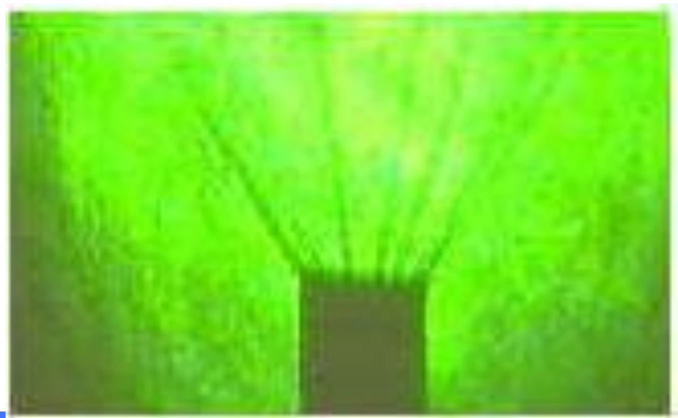
- Class Cleanroom
- Thin Film Synthesis
- Optical Fiber Material



Particle Transport mechanism near the wafer surface

High-Efficiency Energy System

- High-Efficiency Combustion
- Energy Apparatus



Good Aerosols and Bad Aerosols

Bad Aerosols: air pollution, smog,
smoking, asian dust,
virus or bacteria aerosols,
volcano eruption

Good Aerosols: aerosol processing of materials
: optical fibers, paints,cosmetics,
carbon blacks, aerosol drugs
nanoparticles

Air Pollution : Smog

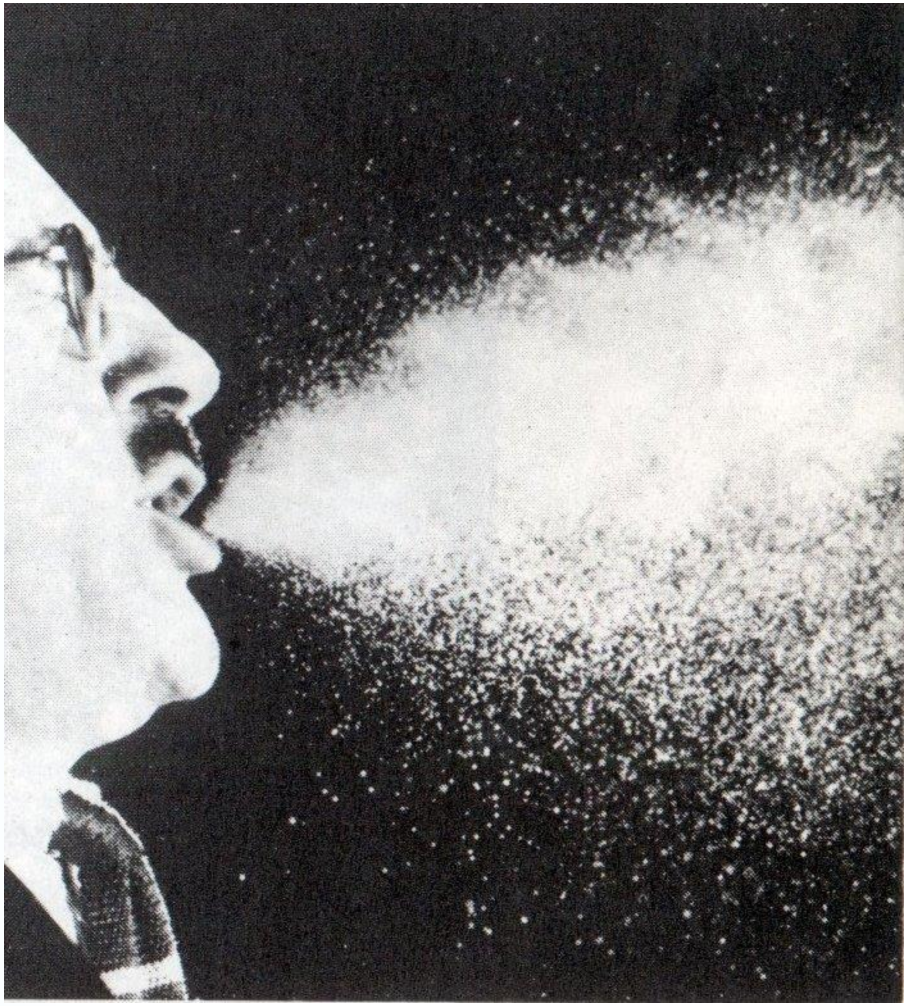
 

Air Pollution

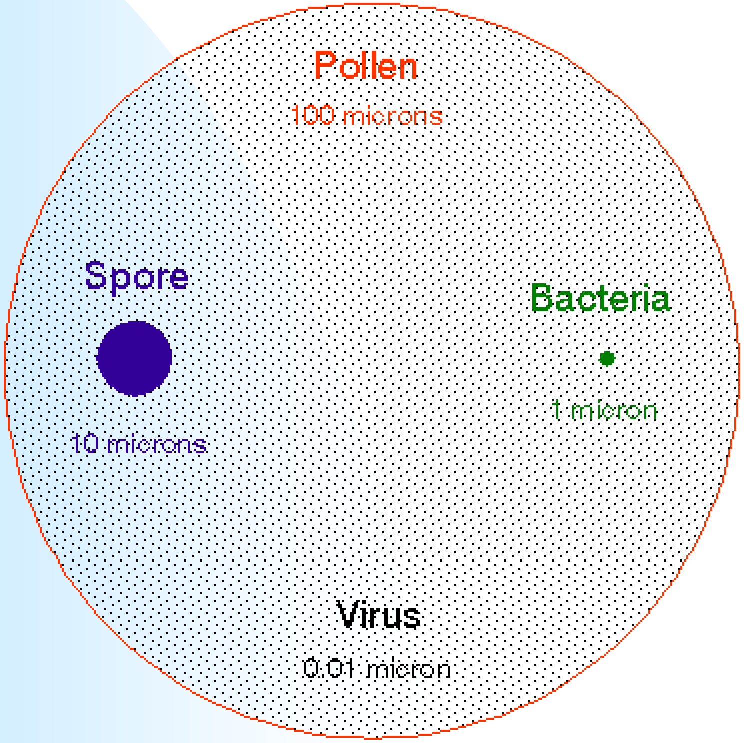
Indoor Air Pollution : Smoke
(carcinogen material for lung cancer)

Volcano Eruption

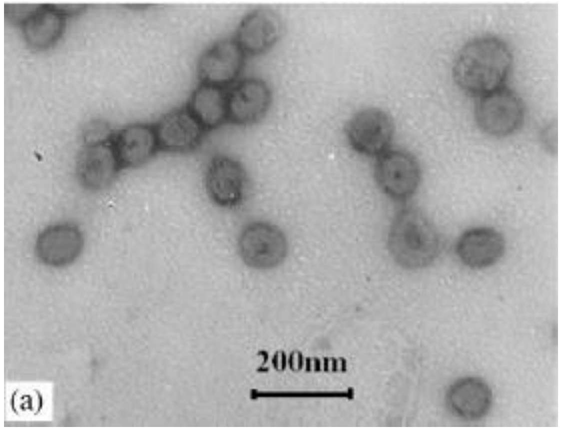
Bioaerosols



Bioaerosols

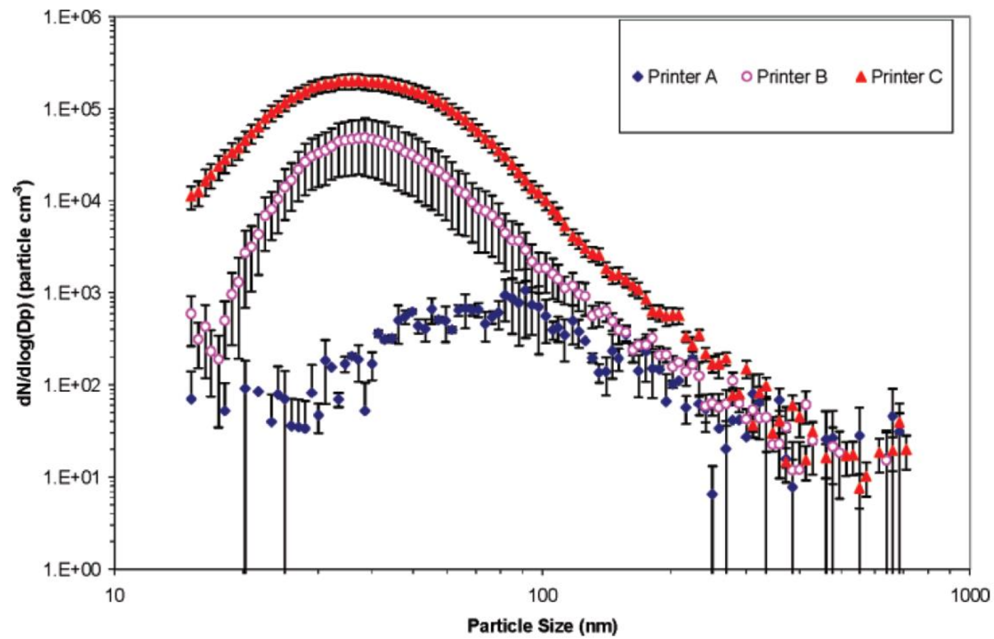


scale representation of the relative size of pollen, pollen spores, bacteria and viruses



Microscopic photographs of *Influenza virus*

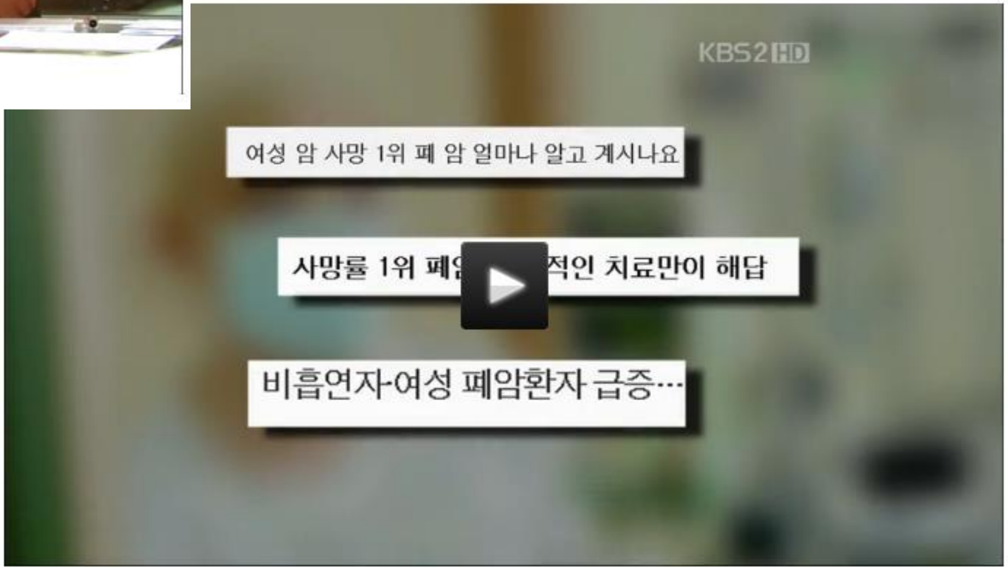
Environment Technology (ET):
Indoor Aerosols from printers, copy machines



Morawska Group , Environ. Sci. Technol. 2007, 41, 6039-6045

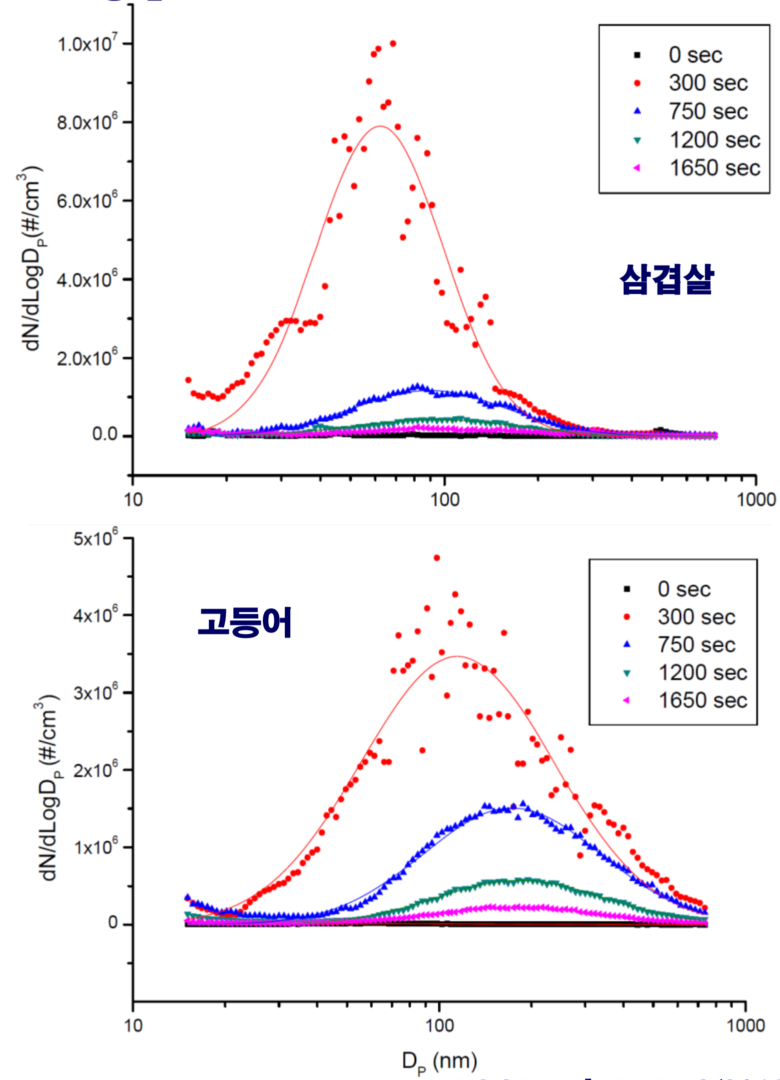
[건강충전] 부엌 연기가 폐암을 유발한다?

KBS 2011.11.04 방송



Environment Technology (ET):

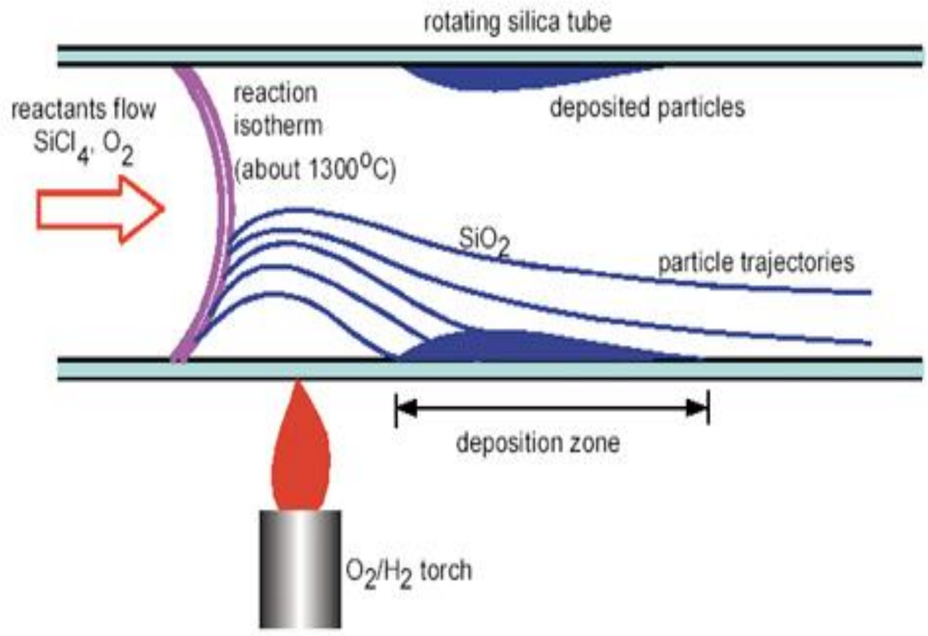
Indoor Aerosols emitted during cooking process



PAAR Vol. 7, No. 3(2011)

Good Aerosols : Optical Fiber ?

- Conventional MCVD



$SiCl_4(g) + O_2(g) \rightarrow SiO_2(s) + 2Cl_2(g)$

Optical fiber

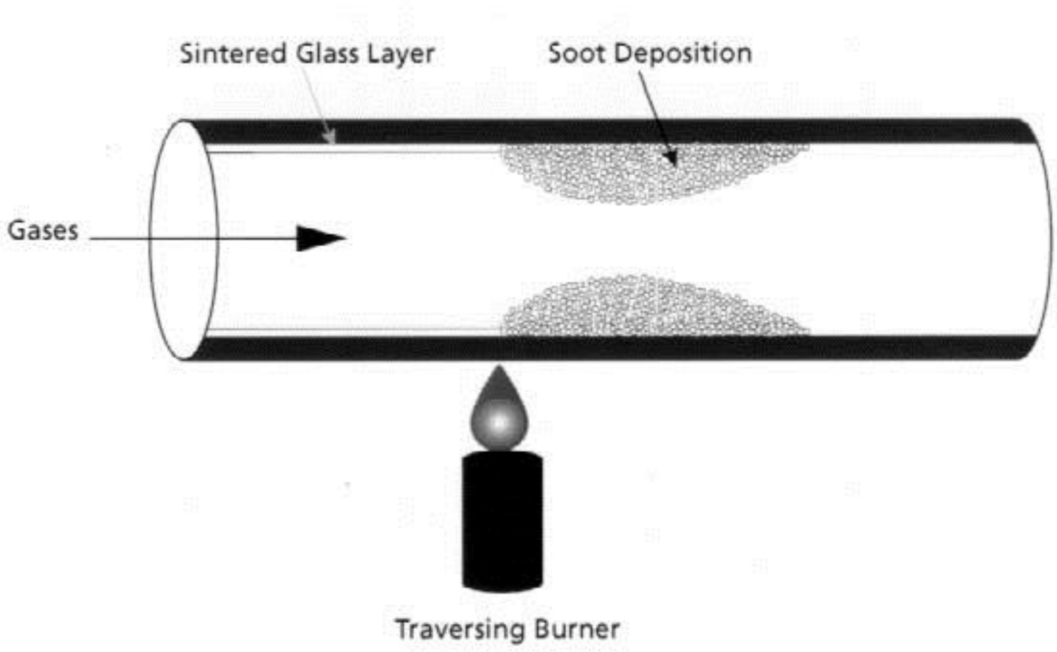
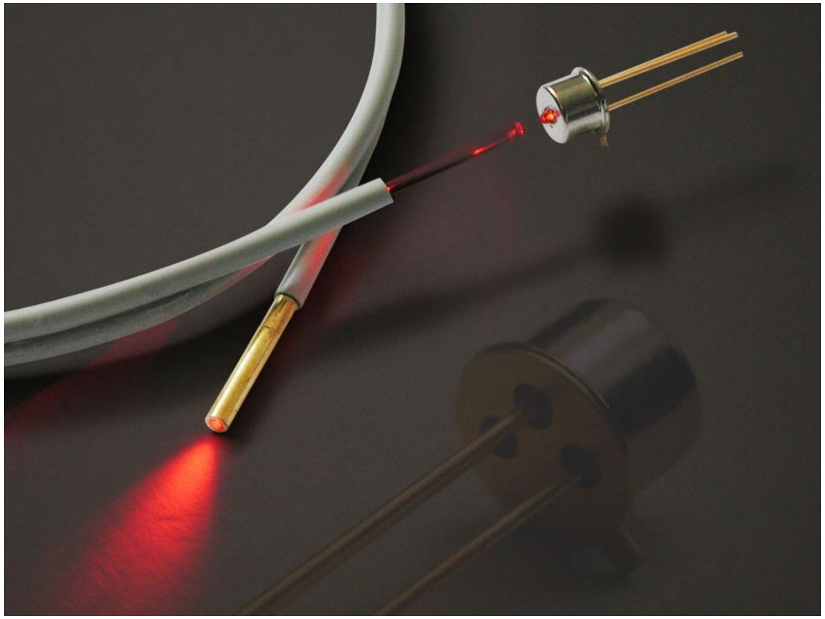
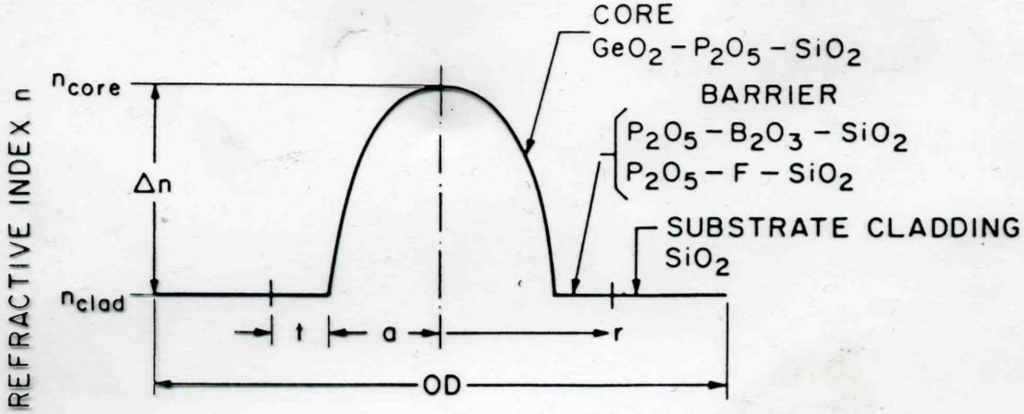


Figure 2 PREFORM FABRICATION

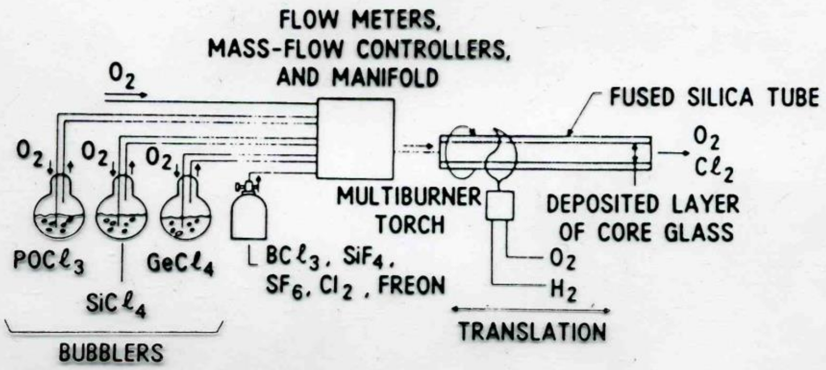


INTRODUCTION

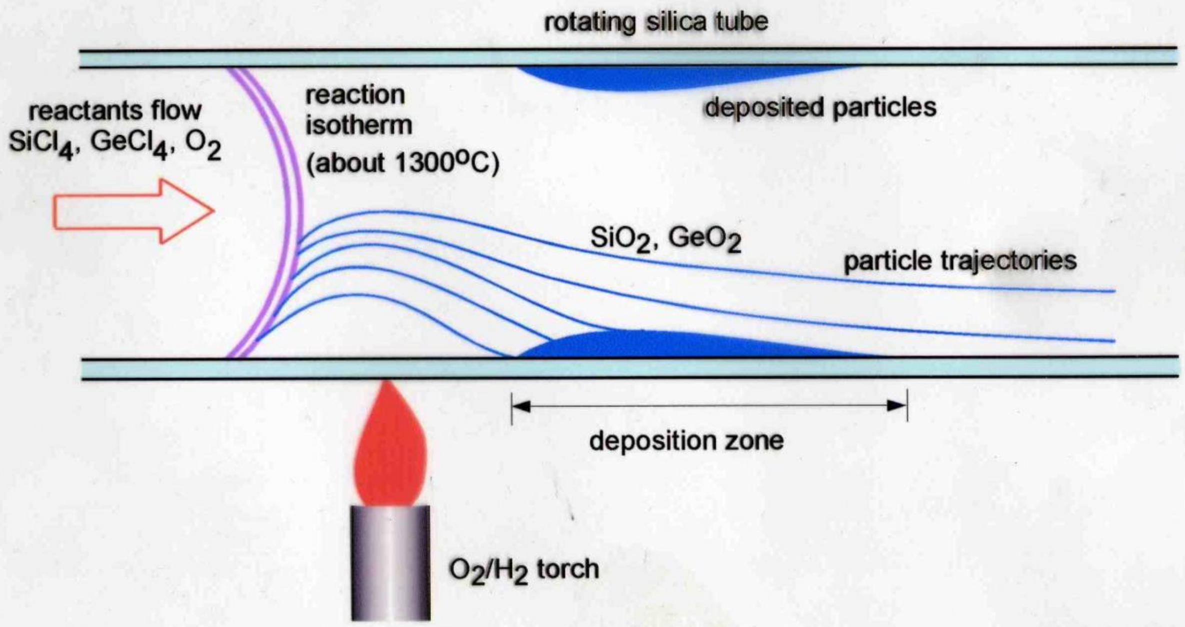
PROFILE OF REFRACTIVE INDEX



MODIFIED CHEMICAL VAPOR DEPOSITION PROCESS



MCVD deposition process



입자의 이동 및 부착현상

- Thermophoresis (열영동)

온도구배가 있는 기체장에 존재하는 입자가 기체분자의 운동량의 교환으로 인해 온도가 높은 곳에서 낮은 곳으로 힘을 받아 이동하는 현상

$$\vec{V} = -K\frac{\nu}{T}\nabla T$$

K : Thermophoretic Coefficient

K = f (d_p, Gas and Particle Properties)

Talbot et al. (1980)

$$K = -\frac{2\nu C_s\left(\frac{k_g}{k_p}+C_t\frac{\lambda}{R}\right)\left(1+\frac{\lambda}{R}\left(A+Be^{-CR/\lambda}\right)\right)}{\left(1+3C_m\frac{\lambda}{R}\right)\left(1+2\frac{k_g}{k_p}+2C_t\frac{\lambda}{R}\right)}$$

⇒ 온도분포의 조절이 증착성능에 직결

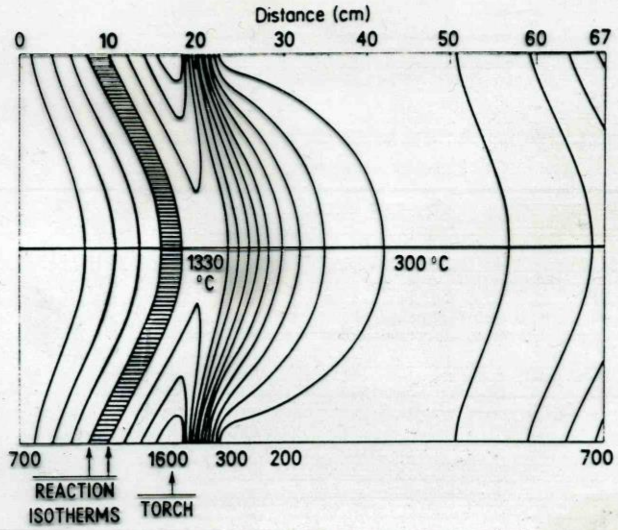


FIG. 5. Temperature field within an MCVD substrate tube relative to torch position.

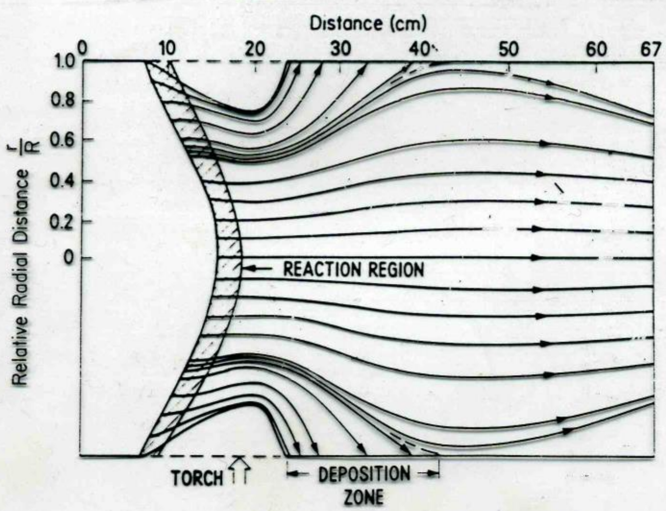
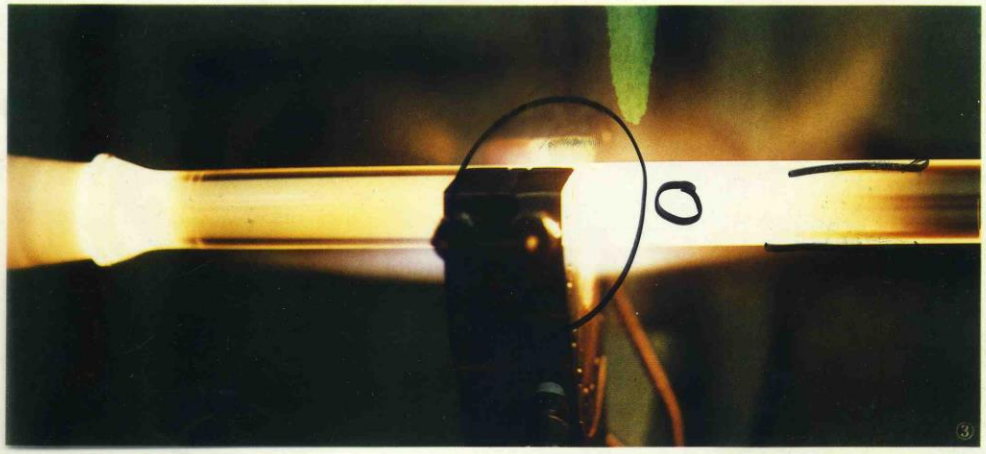
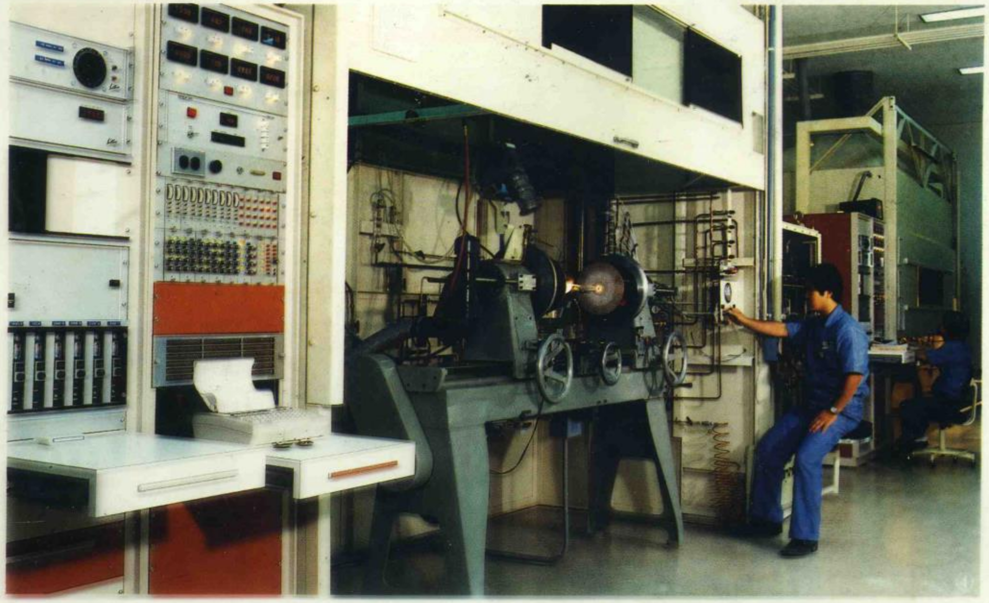


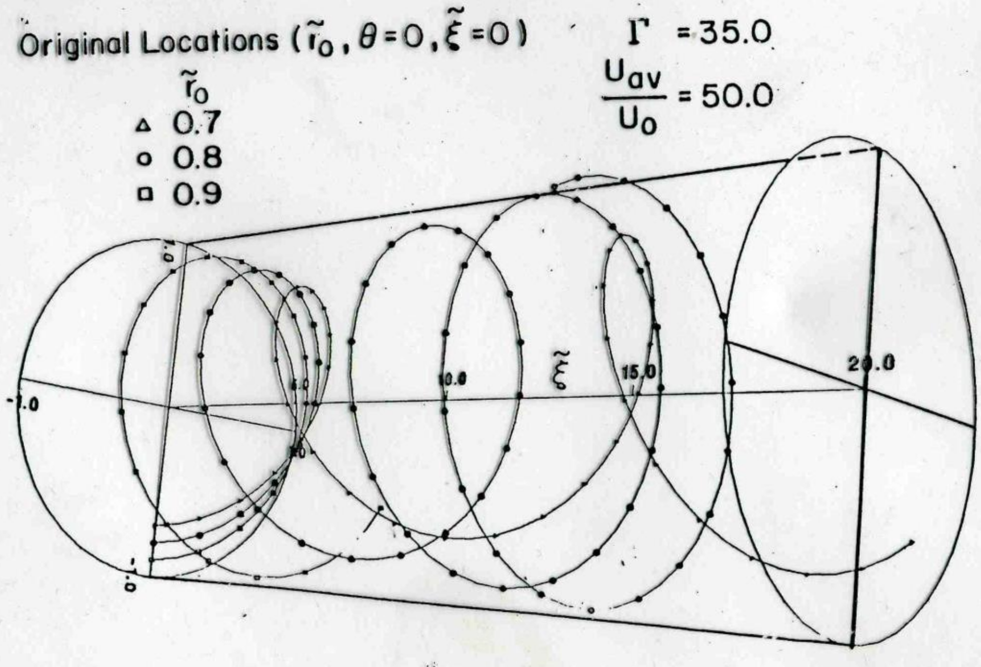
FIG. 6. Particle trajectories resulting from temperature field in Fig. 5.



③



④



PARTICLE TRAJECTORIES; $\lambda = 0.5$, $Pe = 1.0$, $H_M = 3.0$

Good Aerosols : Nanoparticle Synthesis

- Gas Phase Method (Aerosol Method)
- Liquid phase Method (Wet chemistry)

Each method has pros and cons.

- Aerosol method produces purer nanoparticles than wet-chemistry methods
- Aerosol method is continuous process (needed for practical production) while wet-chemistry is a batch process.

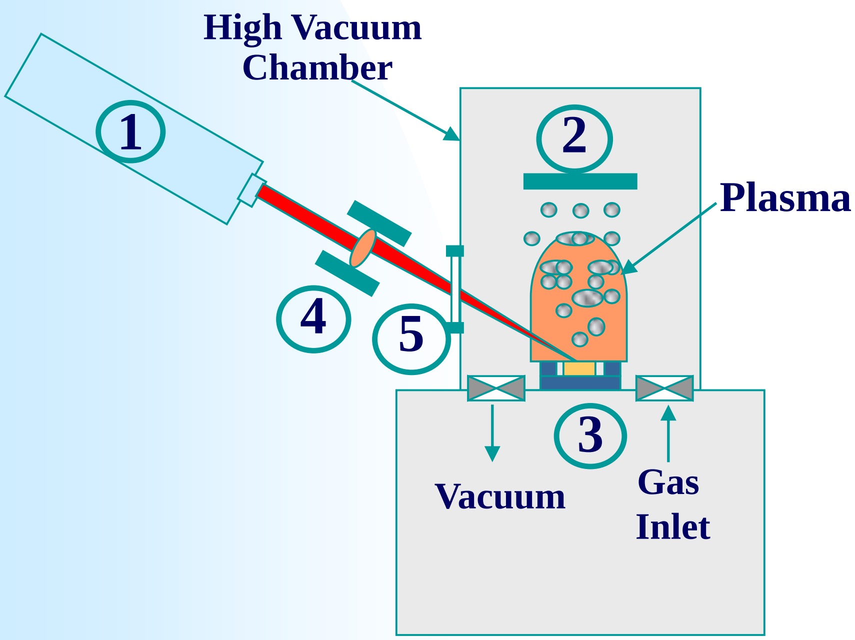
.

Different Aerosol Methods

- **Gas Condensation**
- **Laser Ablation**
- **Thermal CVD**
- **Flame Method**
- **Plasma etc.**

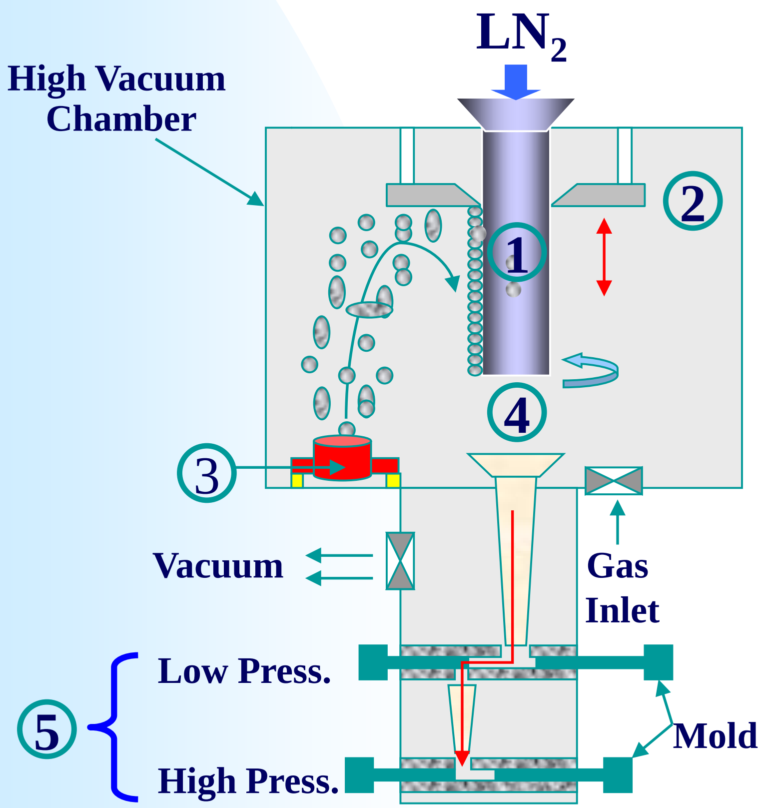
Schematic Diagram of Laser Ablation System

Solid ⇒ Vapor ⇒ Deposition (Film, particle)



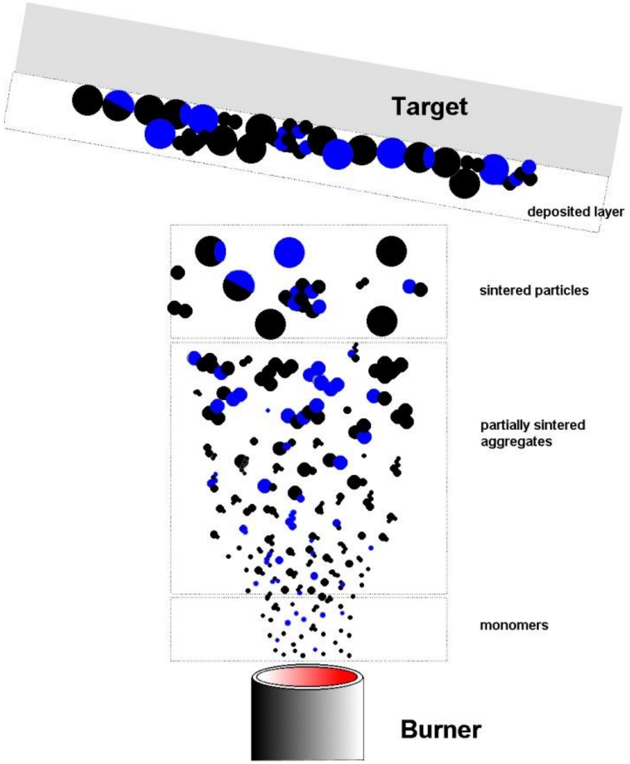
Schematic Diagram of Gas Condensation System

Solid ⇒ Liquid ⇒ Vapor ⇒ Deposition (Film, particle)



Nanoparticle synthesis-Flame Aerosol Synthesis

Pro : high purity nanoparticles at high concentrations
Con : difficulty in controlling the growth of nanoparticles : generation of aggregates when nanoparticles are synthesized at high concentrations.



"How can we synthesize small and unagglomerate sphere nanoparticles at high concentrations?"

SOURCES AND MECHANISMS OF FORMATION OF COMMON AEROSOLS

Aerosol	Mechanism of formation	Agents of formation	Examples
dusts	dispersion of powder or disintegration of matter	nature, wind, human activity	pollen, sandstorm, road dust, fly ash
fog, mist, smoke	condensation from a gas or vapor	condensation	soot, smoke, fog, clouds,condensa-tion nuclei, arti-ficial aerosols
smog, haze	condensation of photochemical reaction products	sunlight	smog, haze, con-densation nuclei
mist, spray	atomization of a solution, evaporation	atomization of a liquid	sea spray, salt nuclei, dust from humidifiers

PARTICLE SIZE

TYPICAL PARTICLE DIAMETERS, ㎛			
Tobacco smoke	0.25	Lycopodium(석송속의 상록식물)	20
Ammonium chloride	0.1	Atmospheric fog	2-50
Sulfuric acid mist	0.3-5	Pollens	15-70
Zinc oxide fume	0.05	“aerosol” spray products	1-100
Flour dust	15-20	Talc(활석)	10
Pigments	1-5	Photochemical aerosols	0.01-1

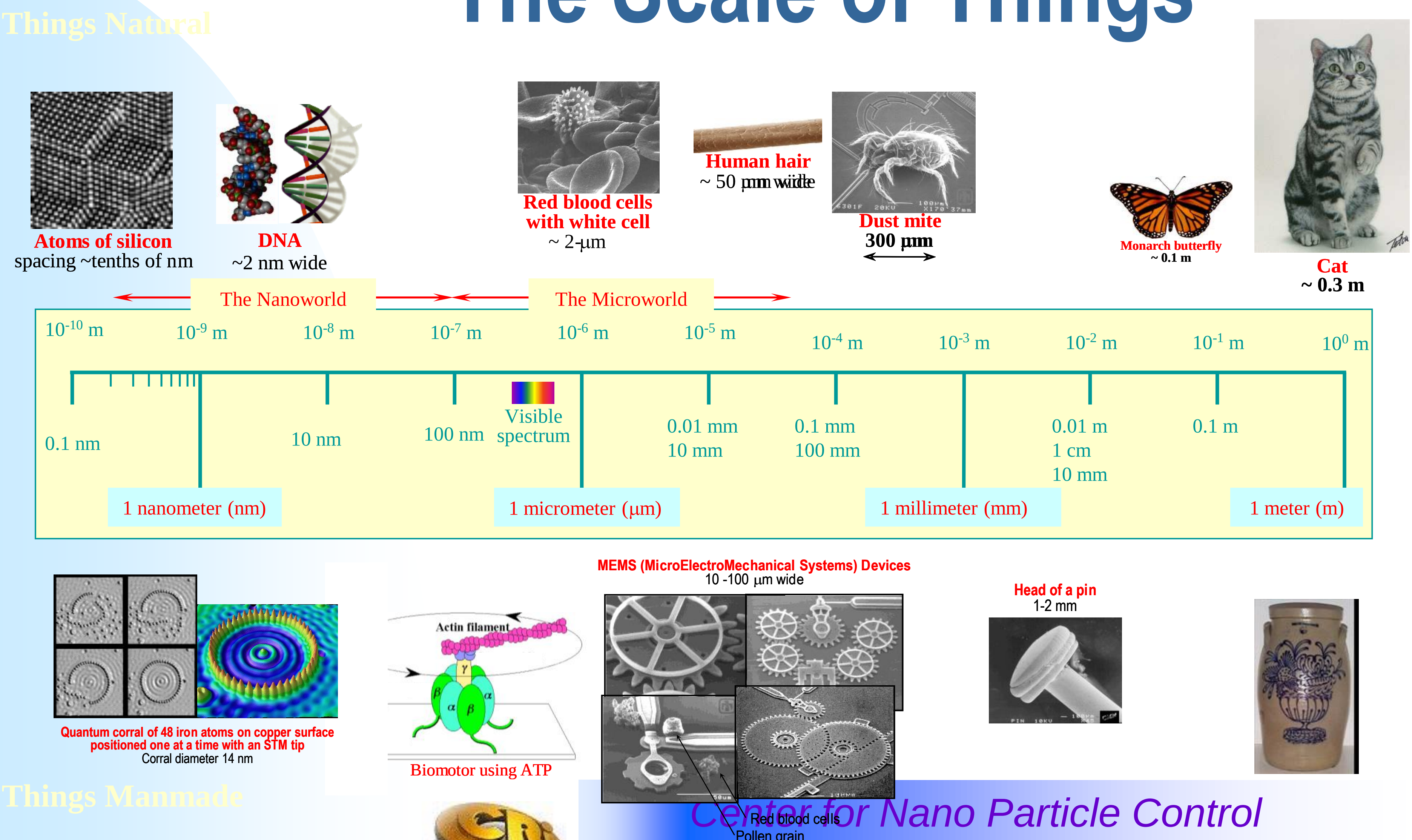
- **Monodisperse – all particles of same size**
- **Polydisperse – all particles of different size**
- **Coarse – particles larger than 1㎛ diameter**
- **Fine – particles less than 1 ㎛ diameter**
- **Ultrafine – particles less than 0.05 ㎛ diameter**

- AGGREGATE – **A group of particles held together by strong atomic molecular forces.**

- AGGLOMERATE – **A group of particles held together by the weaker forces of adhesion of cohesion.**

- FLOCCULATE – **A still weaker grouping of particles easily broken up by gentle shaking of stirring.**

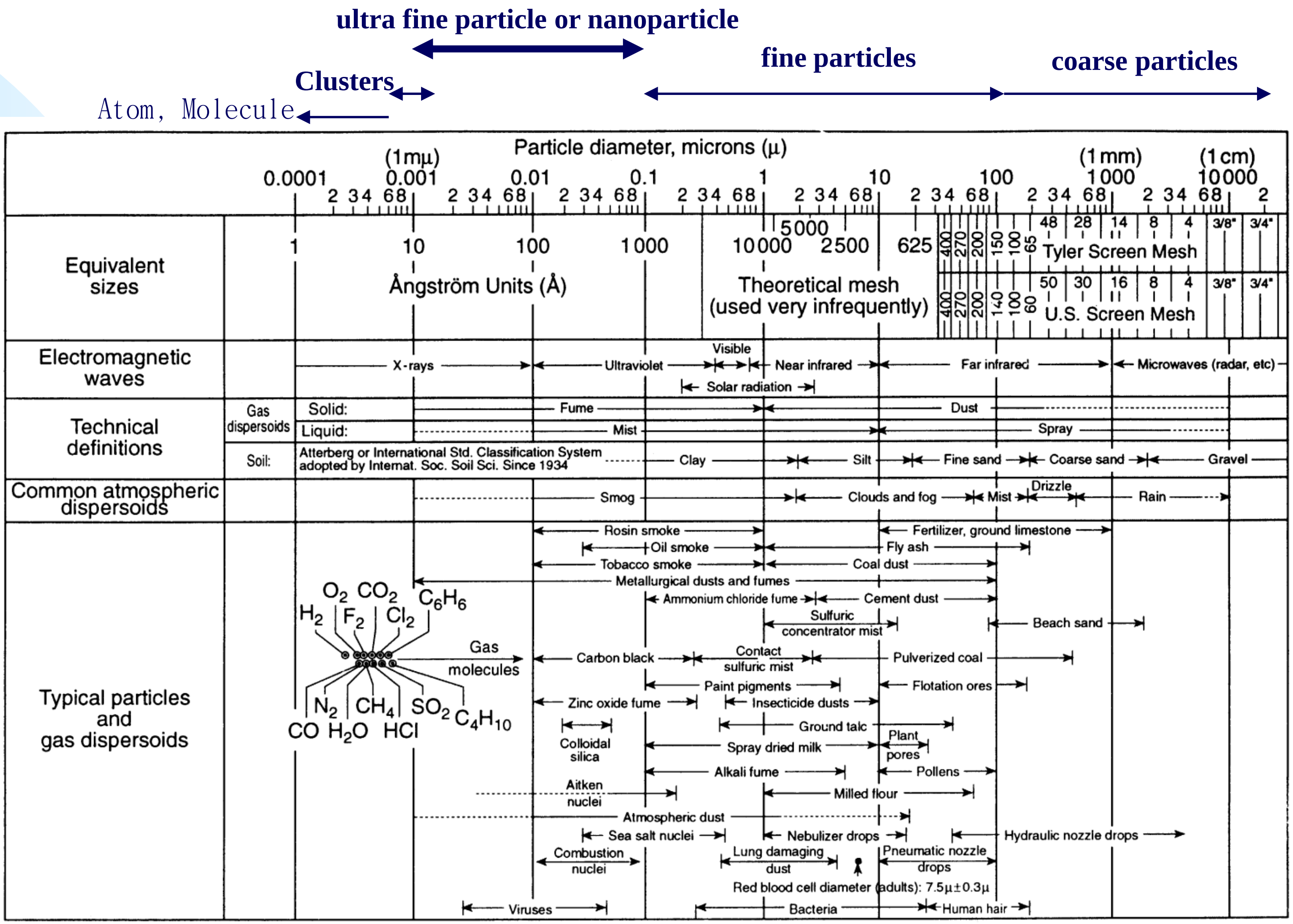
The Scale of Things



Center for Nano Particle Control

Seoul National U., Mechanical & Aerospace Eng.

PARTICLE SIZE



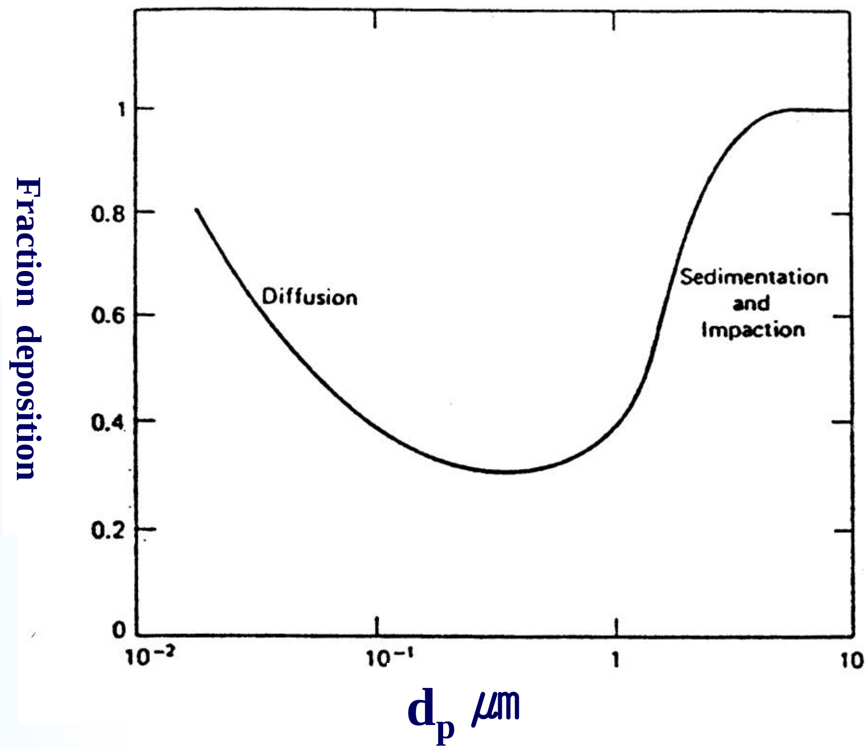
Aerosol measurement, K. Willeke et al., 1993

PARTICLE SIZE

DIAMETER OF AN EQUIVALENT SPHERE

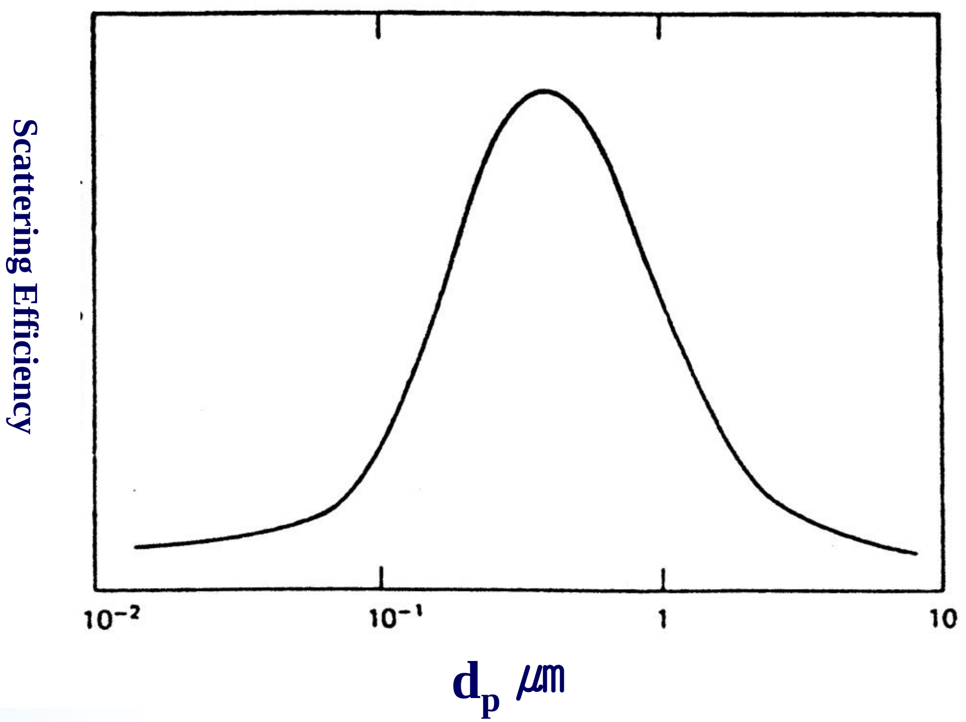
- **Projected area**
- **Surface area**
- **Volume**
- **Mass**
- **Settling speed (Stokes diameter or Aerodynamic diameter)**
- **Electrical mobility**
- **Light scattering**
- **Diffusion coefficient**
- **Etc.**

PARTICLE SIZE



Form of the efficiency curve for particle deposition in the lung. Particles in the range between 0.1 and 1㎛ are too large to diffuse rapidly and too small to settle rapidly or deposit because of inertial effects.

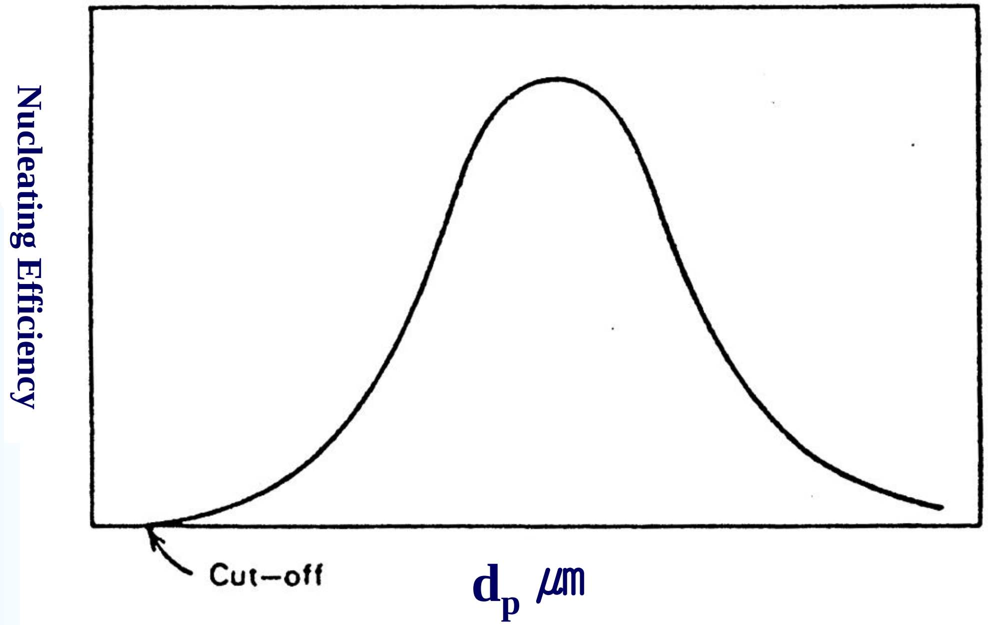
PARTICLE SIZE



Light scattering efficiency, expressed as light scattered per unit mass of particles.

The peak occurs in the range corresponding to the wavelength of the scattered light in the visible range.

PARTICLE SIZE



Nucleating efficiency expressed as rate of condensation per unit mass of aerosol. Particles smaller than the cut-off do not grow because of the increased vapor pressure over a small particle (Kelvin effect). Large particles are inefficient because they have less surface area per unit mass.

PARTICLE CONCENTRATION

CONCENTRATION IN ATMOSPHERE

	Number Concentration, cm^{-3}
Stratosphere(성층권)	0.1
Antarctica	1
Marine surface background	400
Clean continental background	2,000
Average background	9,000
Average urban	140,000
Urban free way	2,000,000

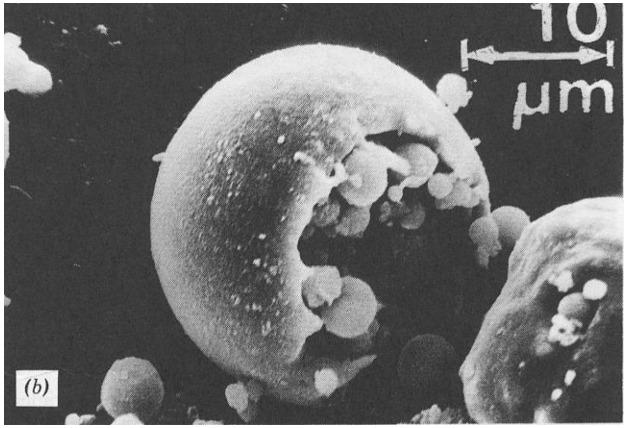
PARTICLE CONCENTRATION

PARTICLE CONCENTRATION IN CLEAN ROOMS

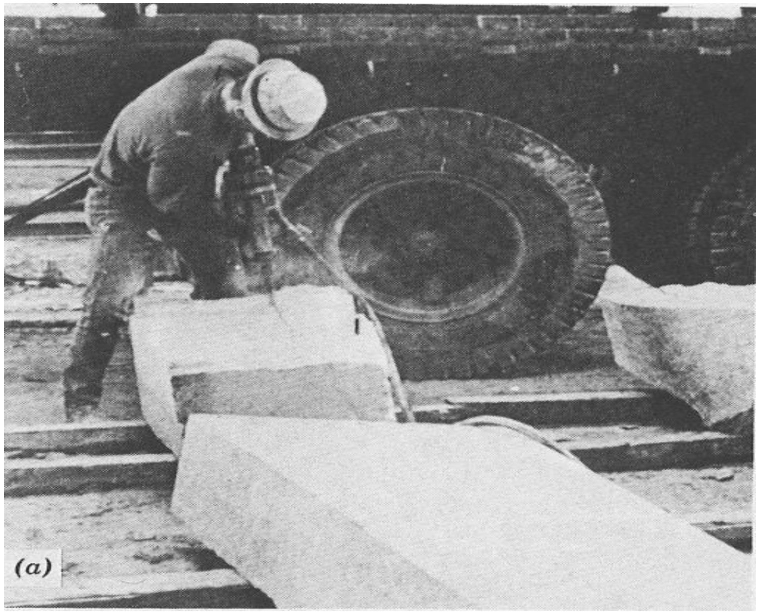
Federal Standard 209B (1973)

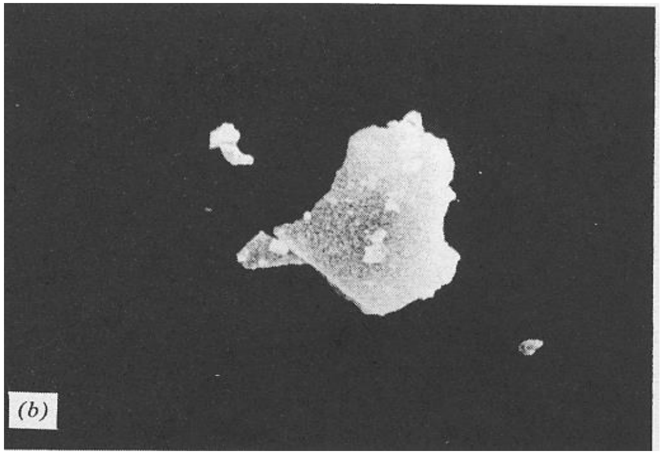
- **Class 100,000 clean room : less than 100,000 particles per cubic foot larger than 0.5 ㎛**
- **Class 10,000 clean room : less than 10,000 particles per cubic foot larger than 0.5 ㎛**
- **Class 100 clean room : less than 100 particles per cubic foot larger than 0.5 ㎛**

Coal burning power plant

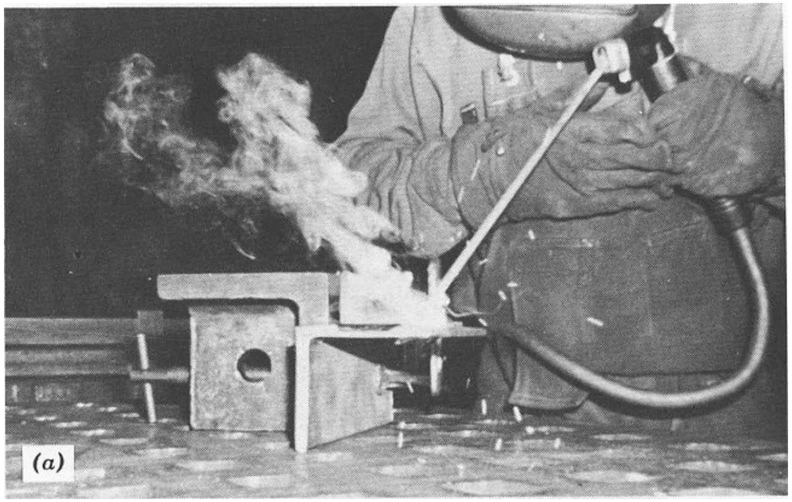


Coal fly ash particles

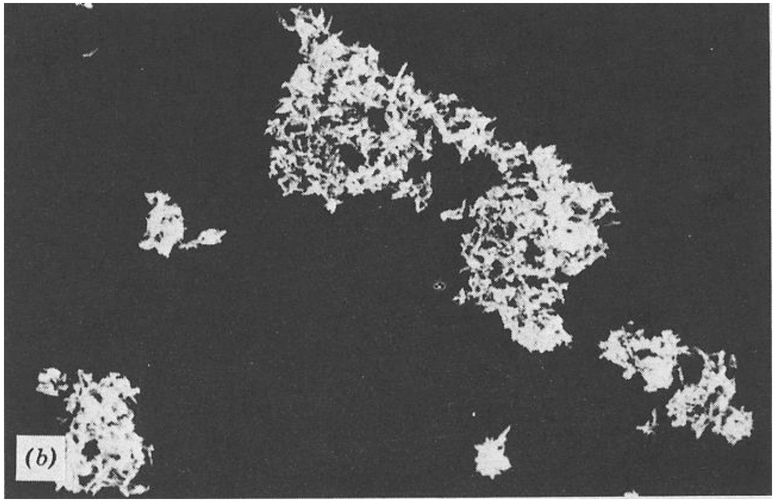




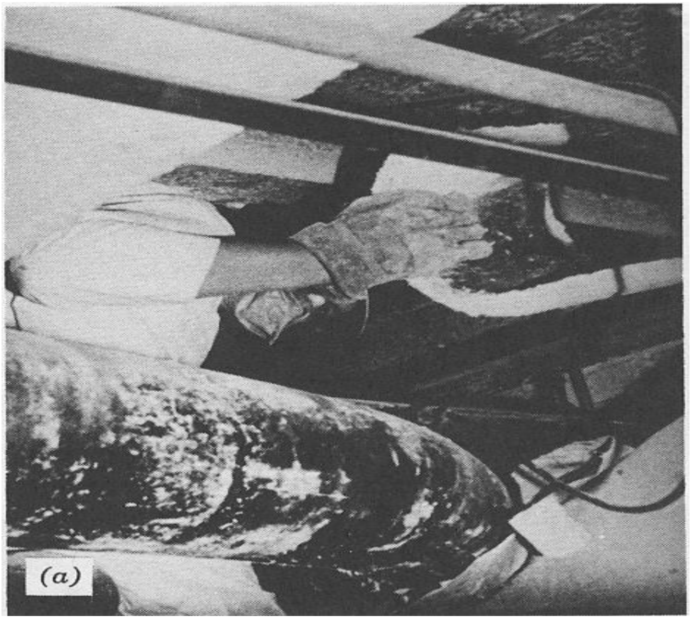
Granite cutting



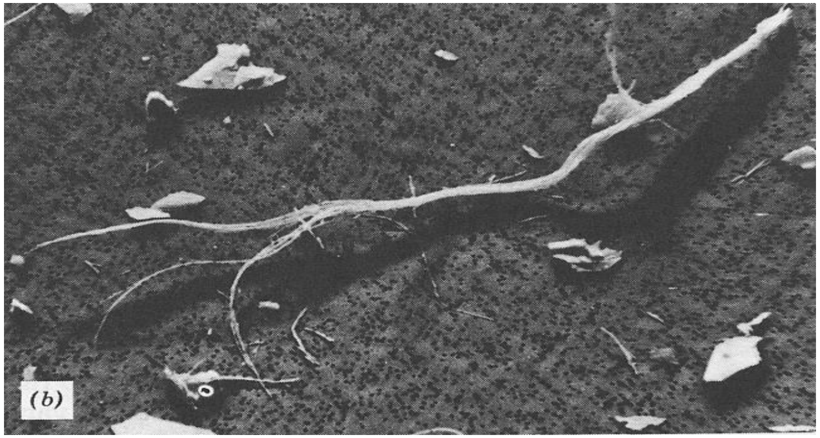
Arc welding

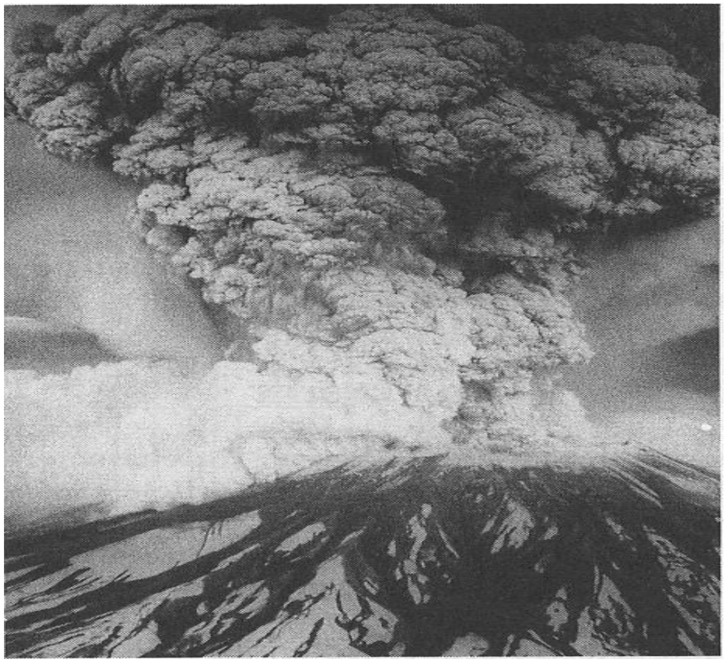


Iron oxide particle

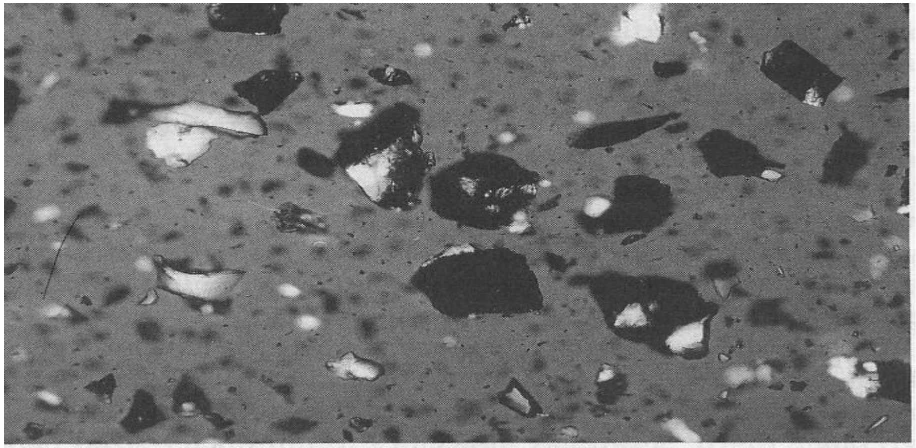


asbestos

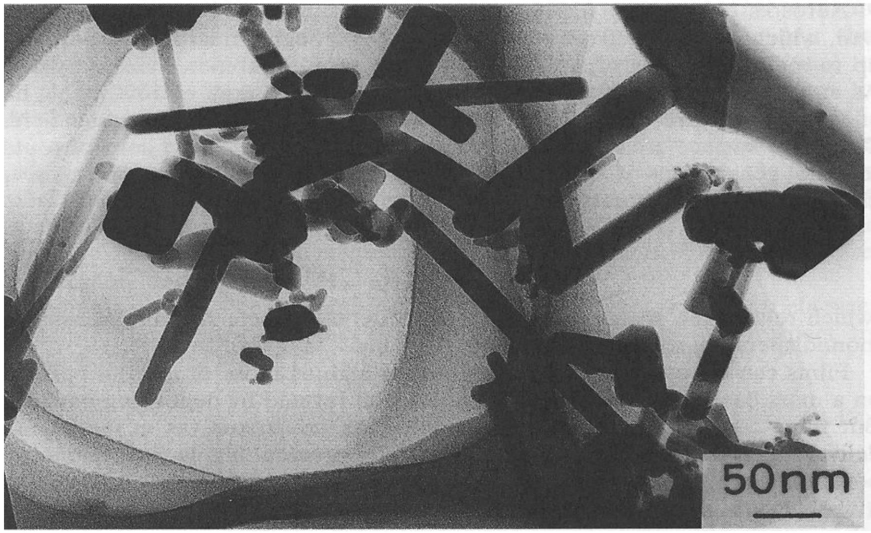




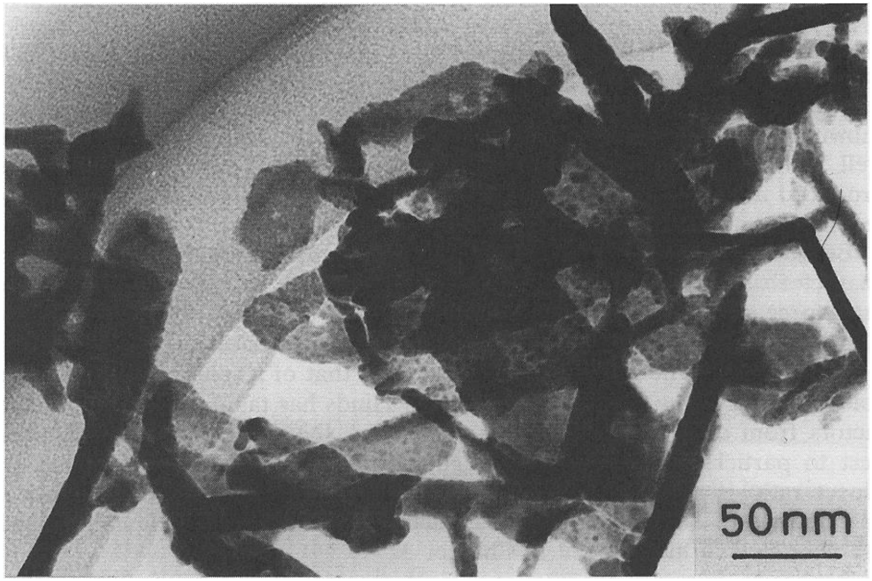
Volcano erruption of Mt.St. Helens, 1980



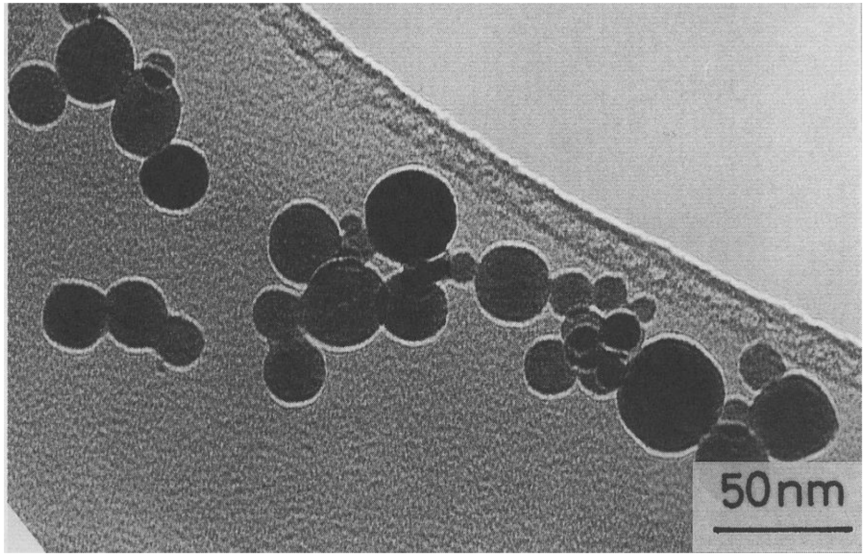
Volcanic ashes



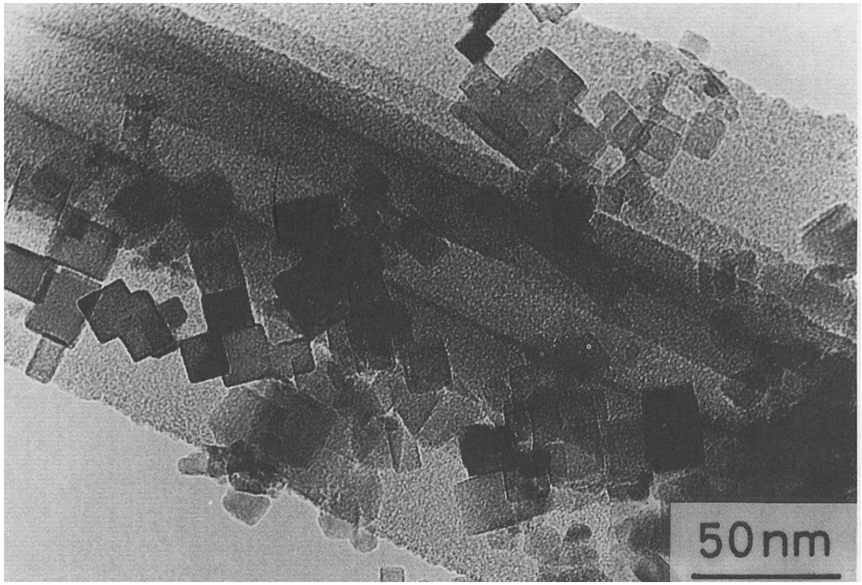
ZnO



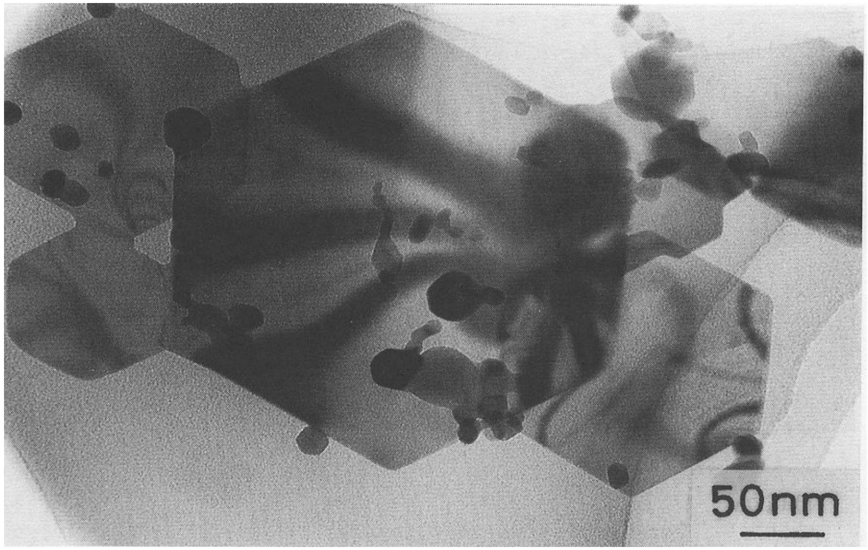
PbO



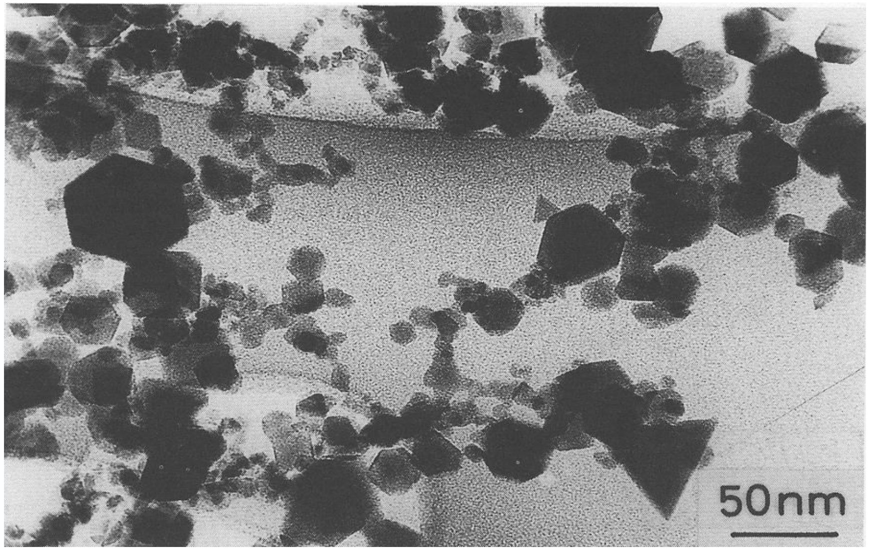
CaMoO4



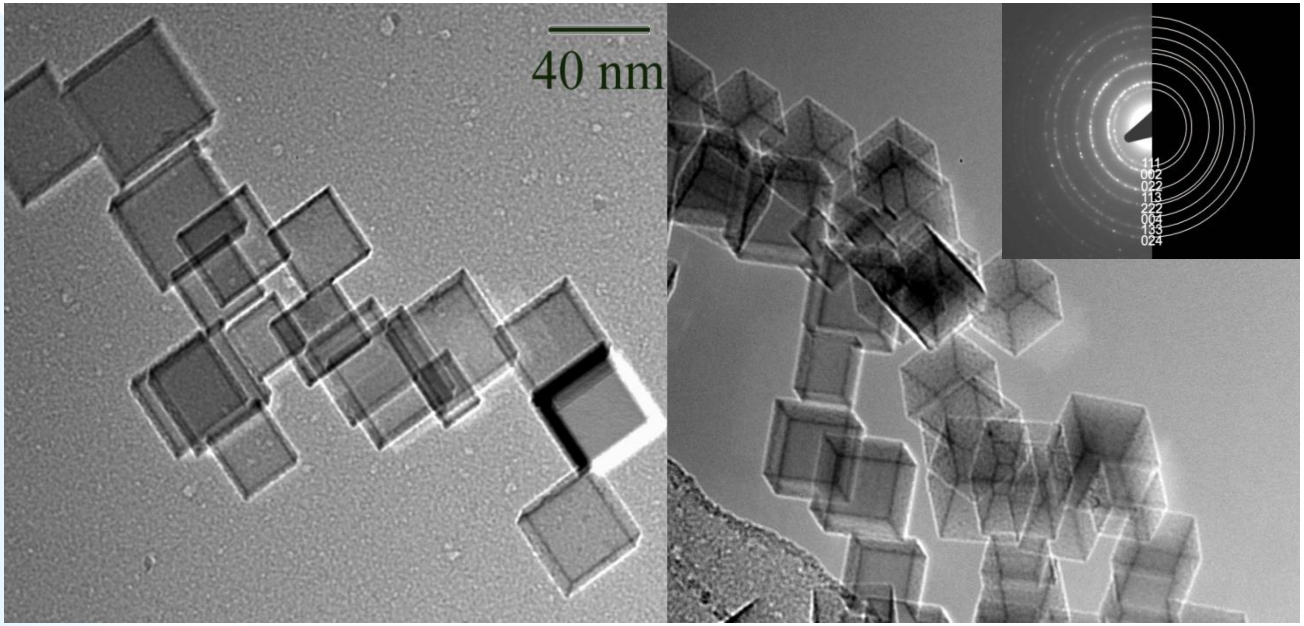
MgO



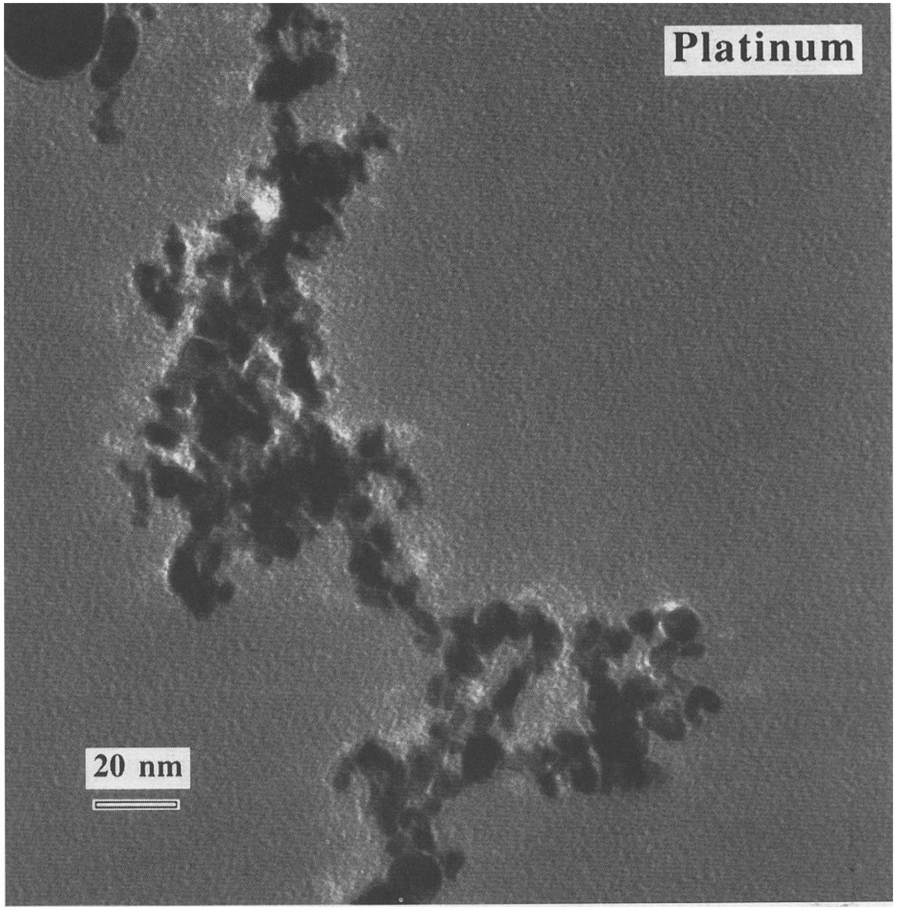
Nd2O3

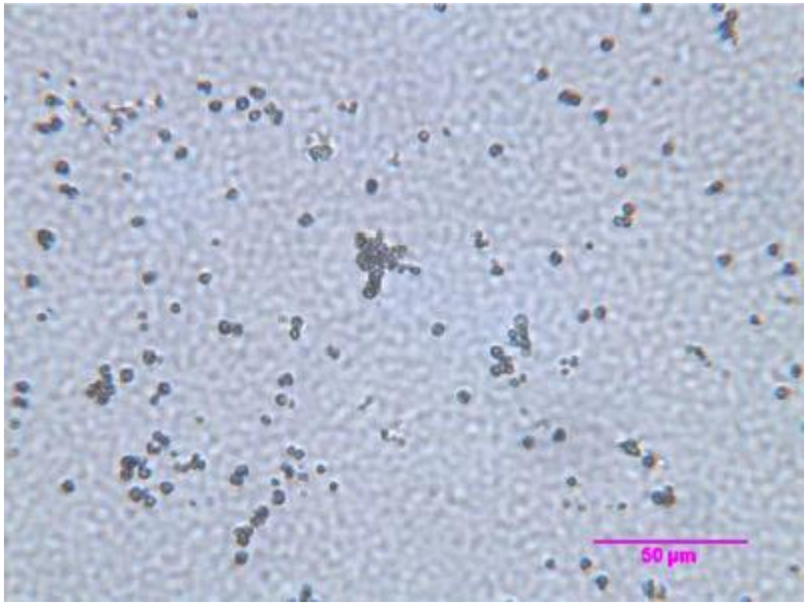


Fe2O3

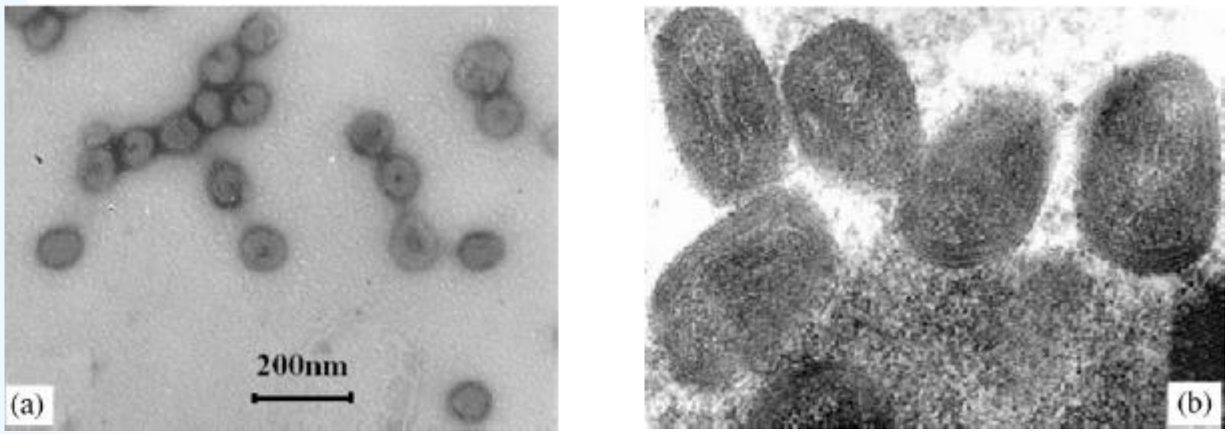


- **Unagglomerate perfect nanocubes of MgO nanocrystals**


Platinum
20 nm



Spores of the laboratory-aerosolized *P. brevicompactum*



Microscopic photographs of the test viruses: *Influenza virus* (a), and *Vaccinia(cow pox:우두 virus* (b).