Chapter 8

Particulate Matter (PM)

Particulate Matter (PM)

DEFINITION

- The term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. The size, length of time in the atmosphere, and sources of these particles vary.

CONCERNS

- PM is the cause of many health problems, especially among people with lung and heart problems.
- Harms the environment by settling on land and soil and changing the chemical balance. (ex. Making lakes acidic, stripping soil of nutrients).
- Cause visibility problems.

The Nature of Particulate Pollutants

Non-homogeneous pollutants

Particulate pollutants:

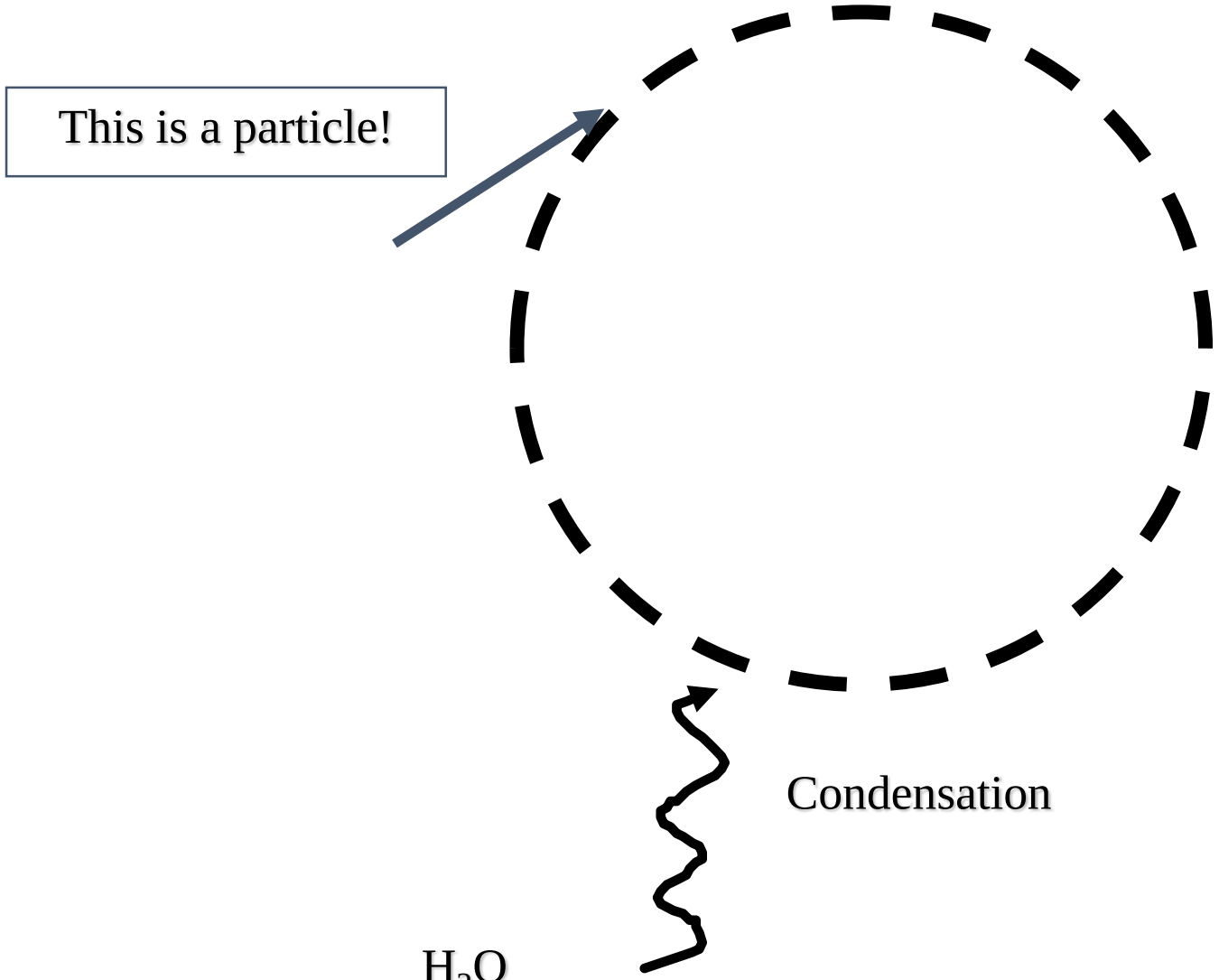
- ❑ have different physical properties (different size, shape, …)

- ❑ not chemically uniform (different chemical composition)

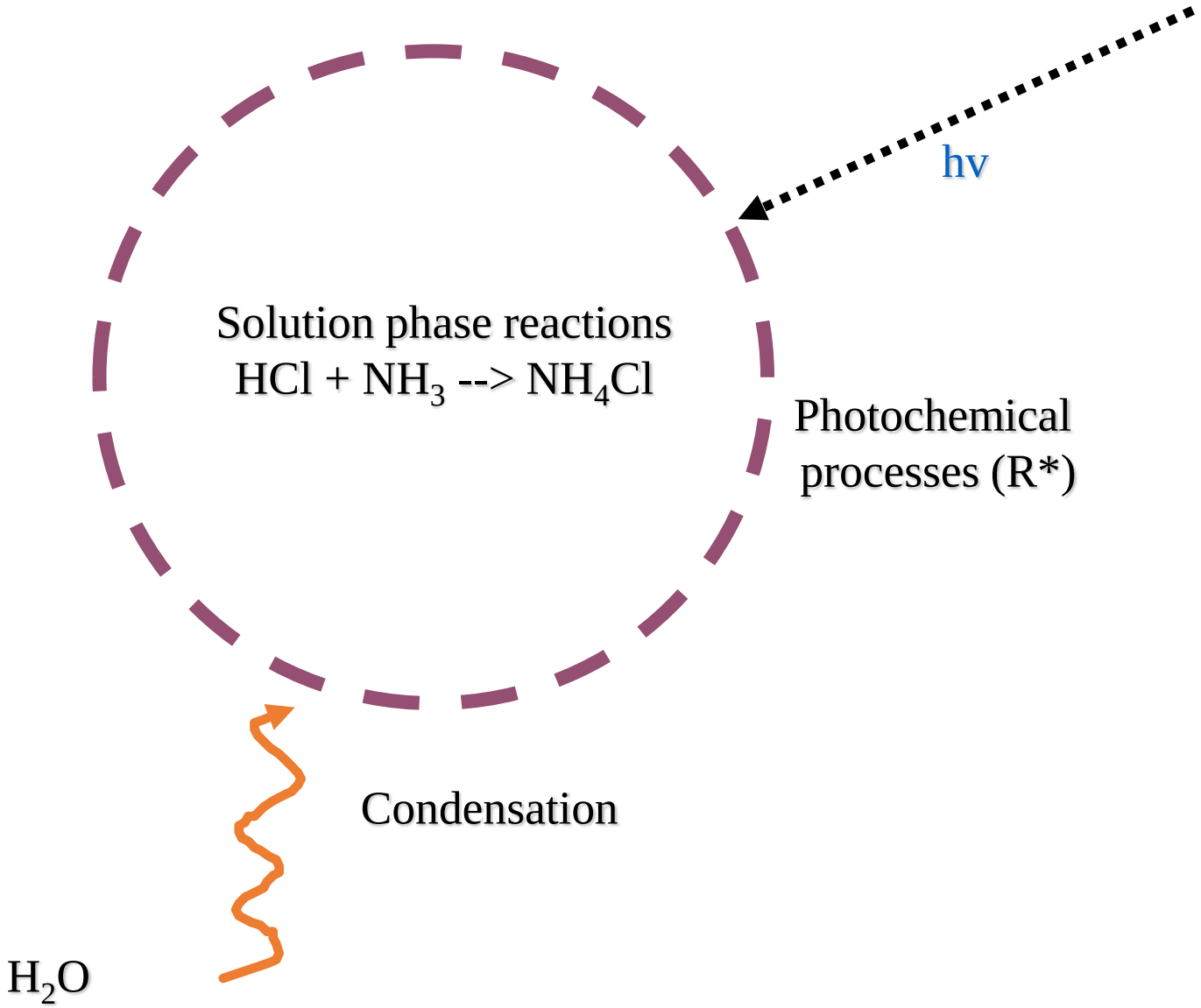
Particles in the Atmosphere

- Aerosols: solids and liquids 100 μm ---->0.5 mm (sand)
- Particles: 1 nm (cluster) ------> 100 μm.
- Particulate material make up most of the visible form of pollution.
- Important in cloud formation, fog formation, heat balance
  - $PM_{2.5}$ is particle matter 2.5 microns or smaller in diameter which is more harmful than larger PMs.

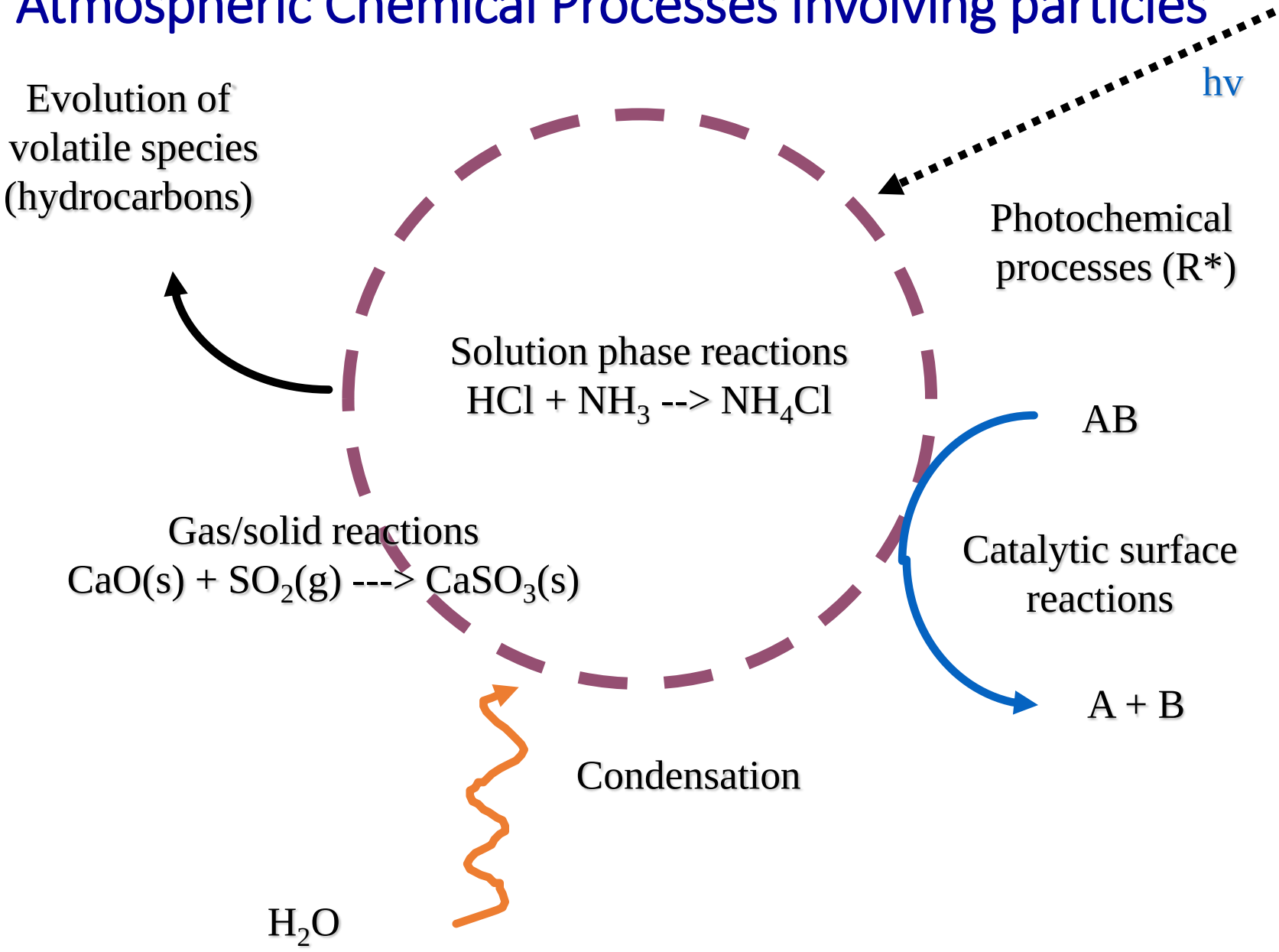
Atmospheric Chemical Processes involving particles



Atmospheric Chemical Processes involving particles



Atmospheric Chemical Processes involving particles



Types of particles

- Transient nuclei (AIKEN) particles 2 nm---> 0.1 μm
  - formed from gas phase condensation (hot vapor)
  - removed by accumulation
- Accumulation range particles 0.1 μm ----> 1 μm

  -formed from low volatility gases and accumulation processes

  -removed by rain

  -these particles do not “settle out of the atmosphere”

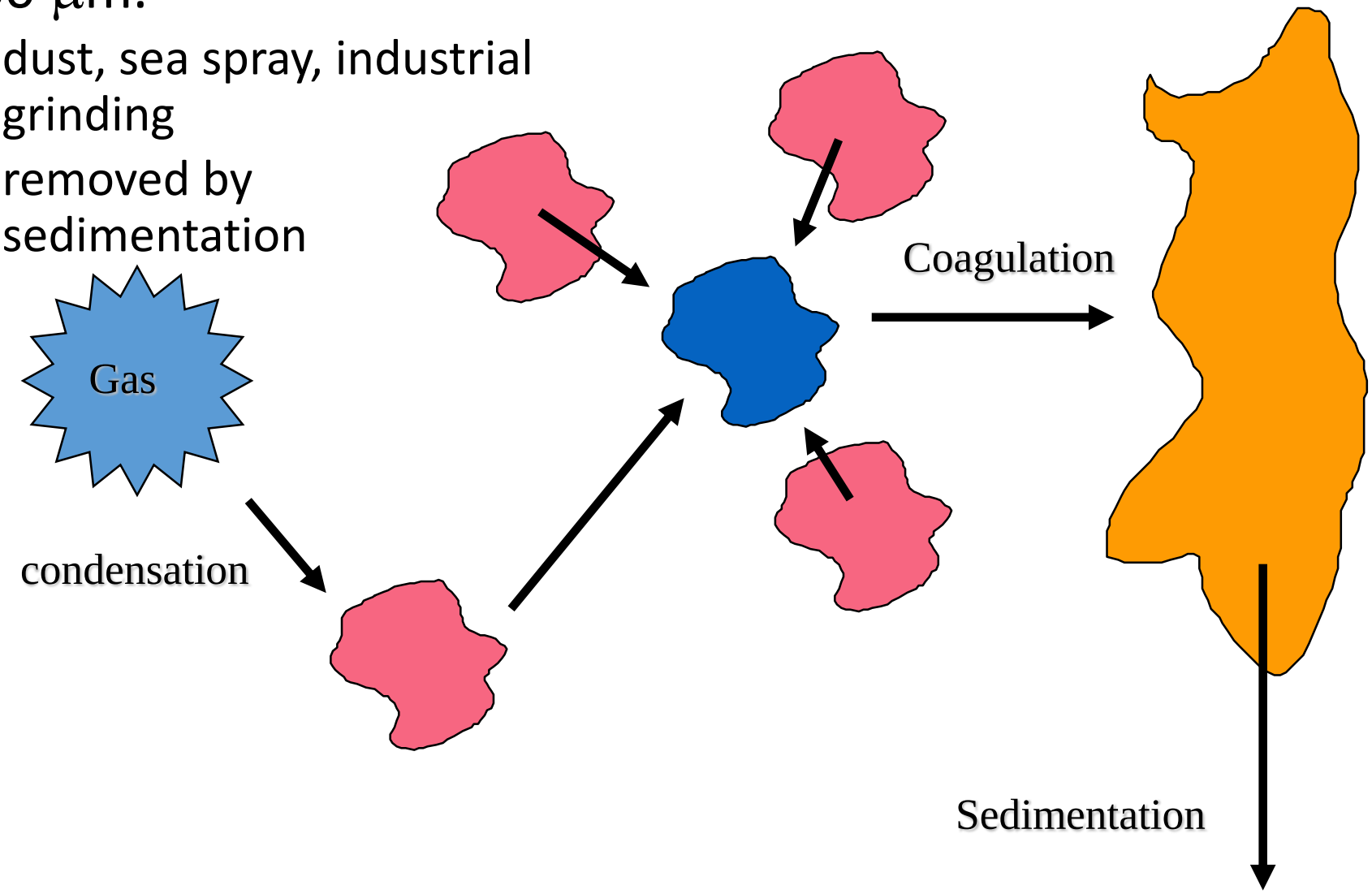
$$CaCO_3 + \text{heat} \Rightarrow CaO + CO_2$$

$$Pb(C_2H_5)_4 + O_2 + halogens \Rightarrow CO_2 + H_2O + PbCl_2$$

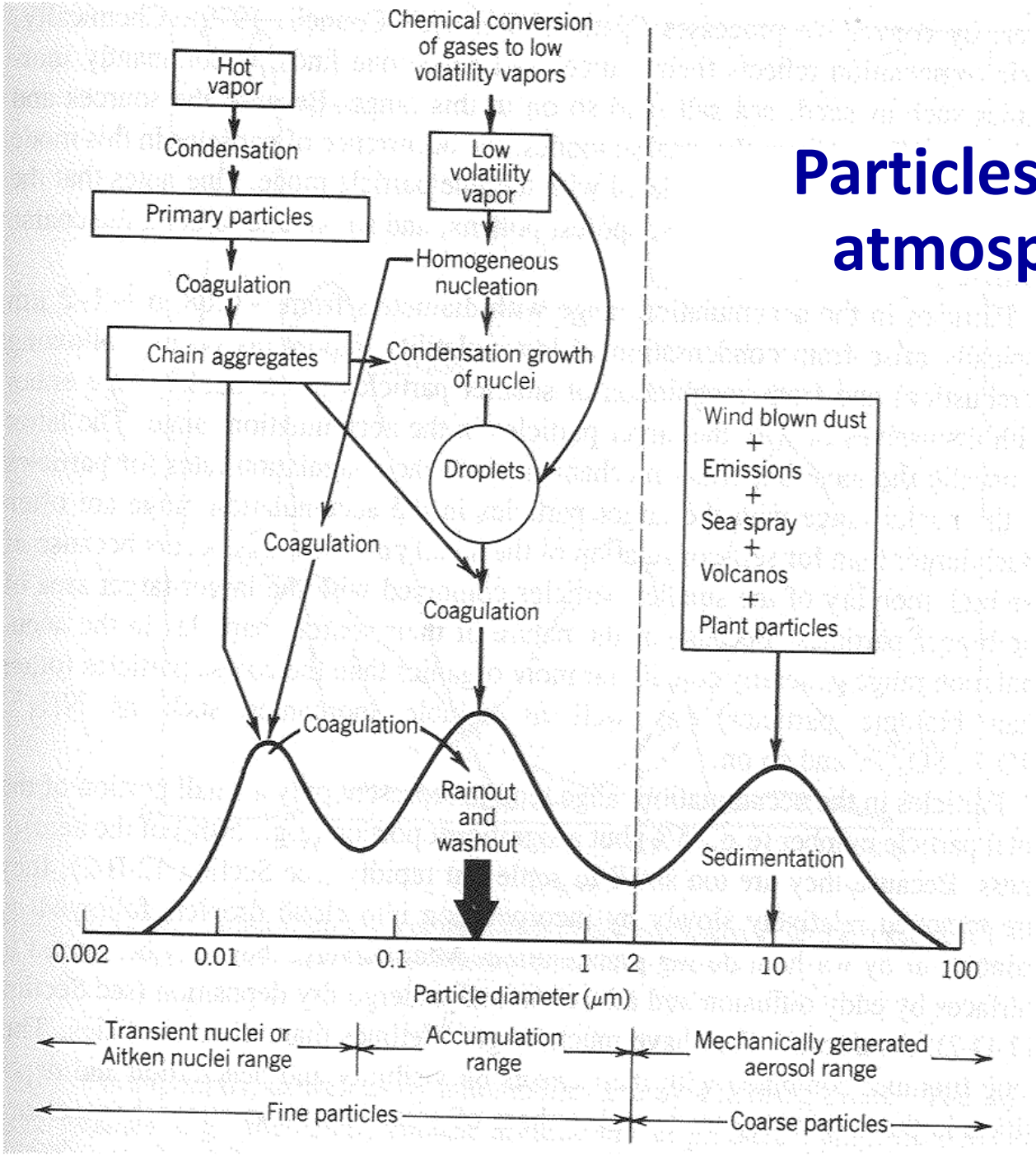
$$2SO_2 + O_2 + 2H_2O \Rightarrow 2H_2SO_4$$

Particulate Matter (PM)

- Course or Mechanically generated particles 1-100 μm.
  - dust, sea spray, industrial grinding
  - removed by sedimentation



Particles in the atmosphere

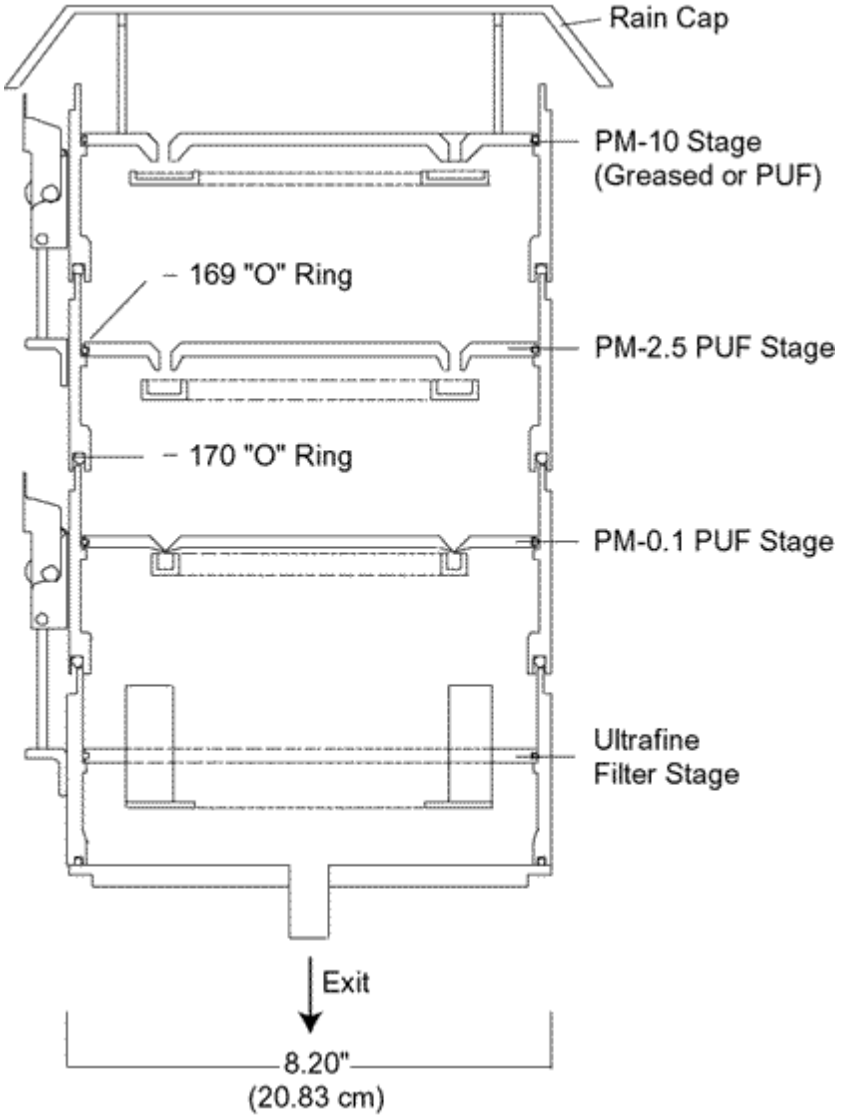


Why do we care about particle size

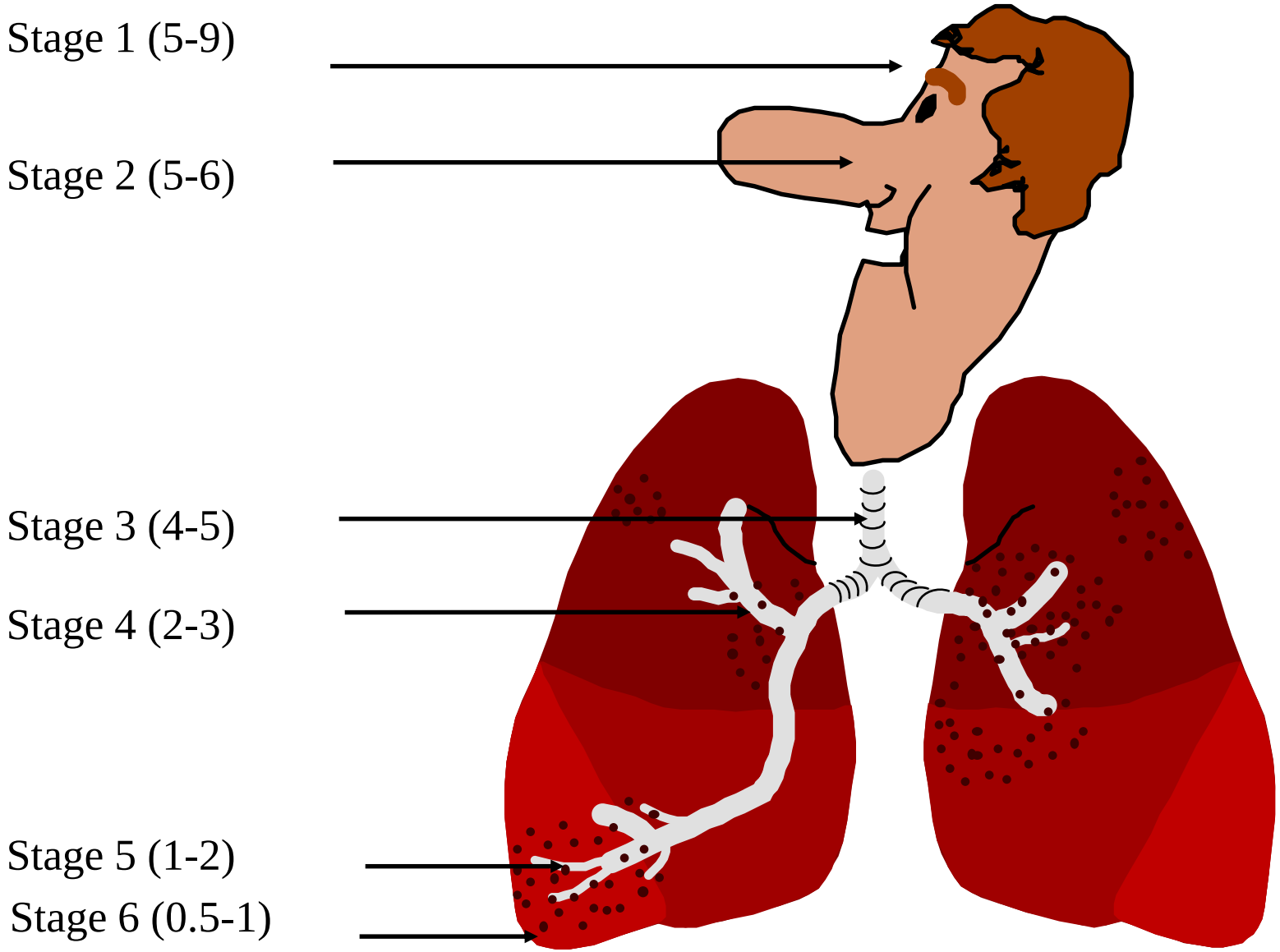
- Health implications
- Transport
- Reactivity
- Information on source functions

- How do we measure particle sizes

Cascade Impactor Design



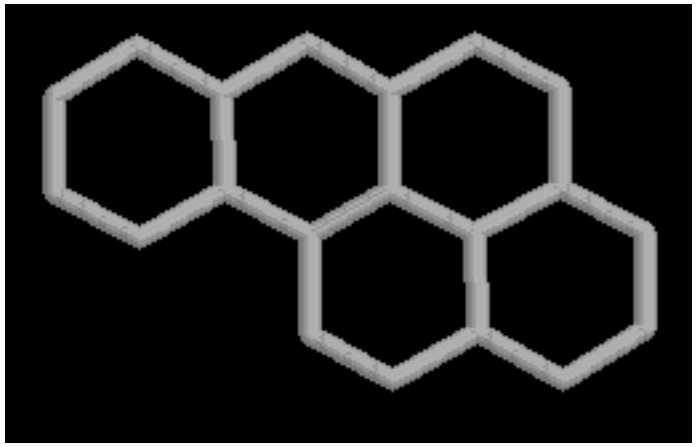
Where do the particles GO?



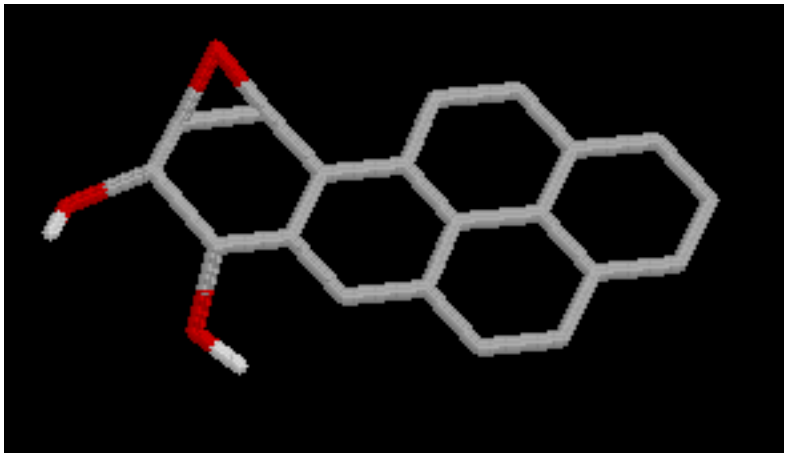
Natural versus anthropogenic emissions of trace metals to the atmosphere

Trace Metal	Anthropogenic	Natural	Natural/total
As	19	12	0.39
Cd	7.6	1.3	0.15
Cr	30	44	0.59
Hg	3.6	2.5	0.41
Pb	332	12	0.04
V	86	28	0.25
(units 10^9 g/yr)			

Organics on Particles (PAH)



benzo[a]pyrene



benzo[a]pyrene-7,8-dihdrodiol
-9,10-dihydroepoxide

Asbestos -Fear and Panic

- What is asbestos?
- Two major types:
  - Serpentine(90%) - fiber bundles (Chrysotile $Mg_6Si_4O_{10}(OH)_8$
  - Amphiboles(10%) - rods
    (Crocidolite $Na_2(Fe3+)_2(Fe2+)_2Si_8O_{22}(OH)_2$)

- Proven carcinogen since 1900's based on lung tumors in asbestos mine workers
- QUESTION: Does the carcinogenicity apply to the general population?

Asbestos

- Why do we use asbestos?
  - fireproofing
  - insulation
  - cement construction
  - friction materials
  - sealants
- Different types of fibers differ in chemical composition, morphology, durability!
- each fiber type must be considered independently

Does it Kill You?

- Yes...but, many questions are unanswered.
- The relationship between exposure and lung cancer is approximately linear, but the slope is a function of type and industrial usage!
- Chrysotite at current occupational levels may not be dangerous (90% of asbestos).
- The US does not differentiate between fibers, Europe does!
- Cost…

EPA expects asbestos removal in 733,000 buildings in the next 30 years ……. $53 - $150 billion dollars!

Particulate Pollutants

I. Stokes law

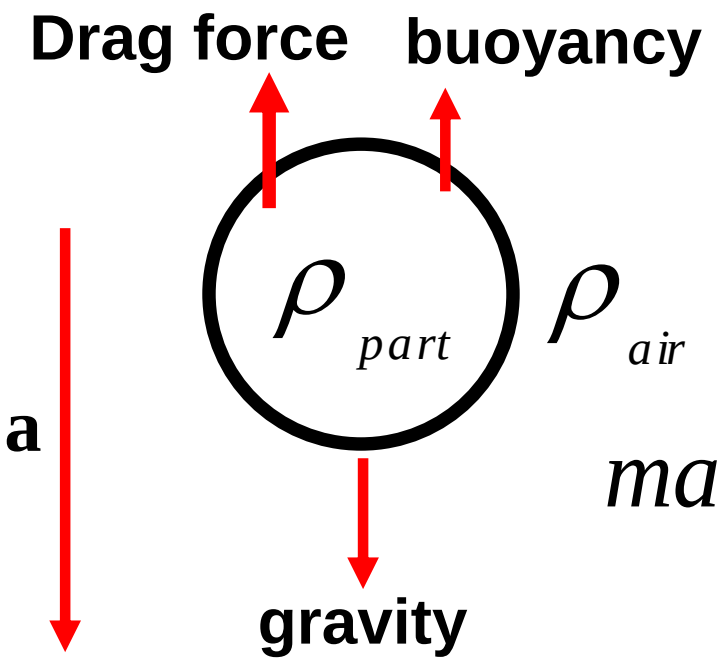
II. Terminal gravitational settling velocity

III. Behavior of Particles in the Atmosphere

IV. Summary

Forces acting on particles in a fluid

$$F_d = 3\pi\mu DV$$



μ : the viscosity of the fluid

According to Newton's law for viscosity

$$ma = Gravity - F_d - Buoyancy$$

$$= \rho_{part}\left(\frac{\pi}{6}\right)D^3 g - \rho_{air}\left(\frac{\pi}{6}\right)D^3 g - Fd$$

$$ma = Gravity - F_d - Buoyancy$$

$$F_d = 3\pi\mu DV$$

The drag force increases as the velocity increases until it equals the gravity minus the buoyancy.

At this time, the velocity is terminal setting velocity, the sum of the forces acting is zero, so the particle continues to move at a constant velocity.

$$0 = Gravity - F_d - Buoyancy$$

$$Fd = \left(\frac{\pi}{6}\right) D^3 g\left(\rho_{part} - \rho_{air}\right)$$

$$F_d = 3\pi\mu DV$$

$$\therefore V = gD^2\left(\frac{\rho_{part} - \rho_{air}}{18\mu}\right)$$

Terminal gravitational settling velocity

$$V = gD^2\left(\frac{\rho_{part} - \rho_{air}}{18\mu}\right)$$

Stokes' law

$$\because \rho_{part} << \rho_{air}$$

So ρ_{air} can be ignored ,

$$V = \frac{gD^2\rho_{part}}{18\mu} \Rightarrow V \propto D^2$$

Terminal gravitational settling velocity

The assumptions of stokes law

① The fluid is continuous.

② The flow is laminar.

③ Newton's law of viscosity holds

④ the terms involving velocities squared are negligible.

Terminal gravitational settling velocity

- Why are we interested in settling velocity?

- What is the relationship between v_t and diameter of particles?

- What is the relationship between v_t and air pollution?
  - primary pollutants
  - secondary pollutants

Terminal gravitational settling velocity

$$V = \frac{gD^2\rho_{part}}{18\mu} \quad \Rightarrow \quad V \propto D^2$$

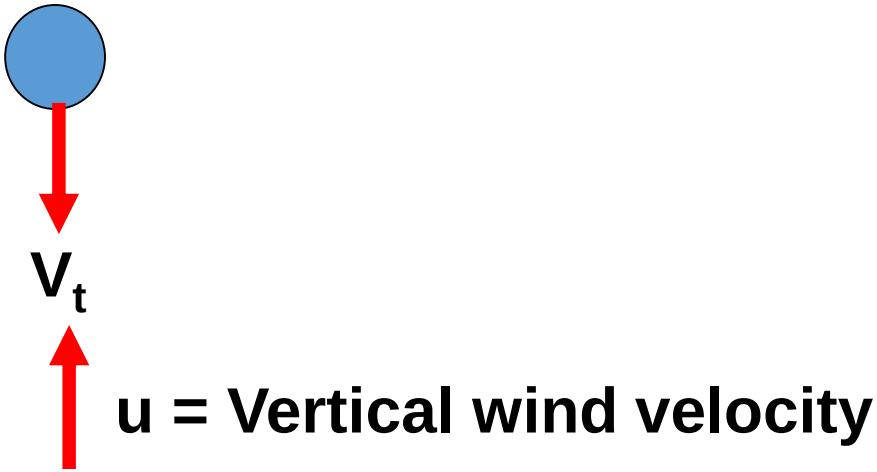
P210, Figure 8.1

1 μ V_t **= 0.006 cm/s**

10 μ V_t **= 0.6 cm/s**

1000 μ V_t **= 600 cm/s**

Terminal gravitational settling velocity



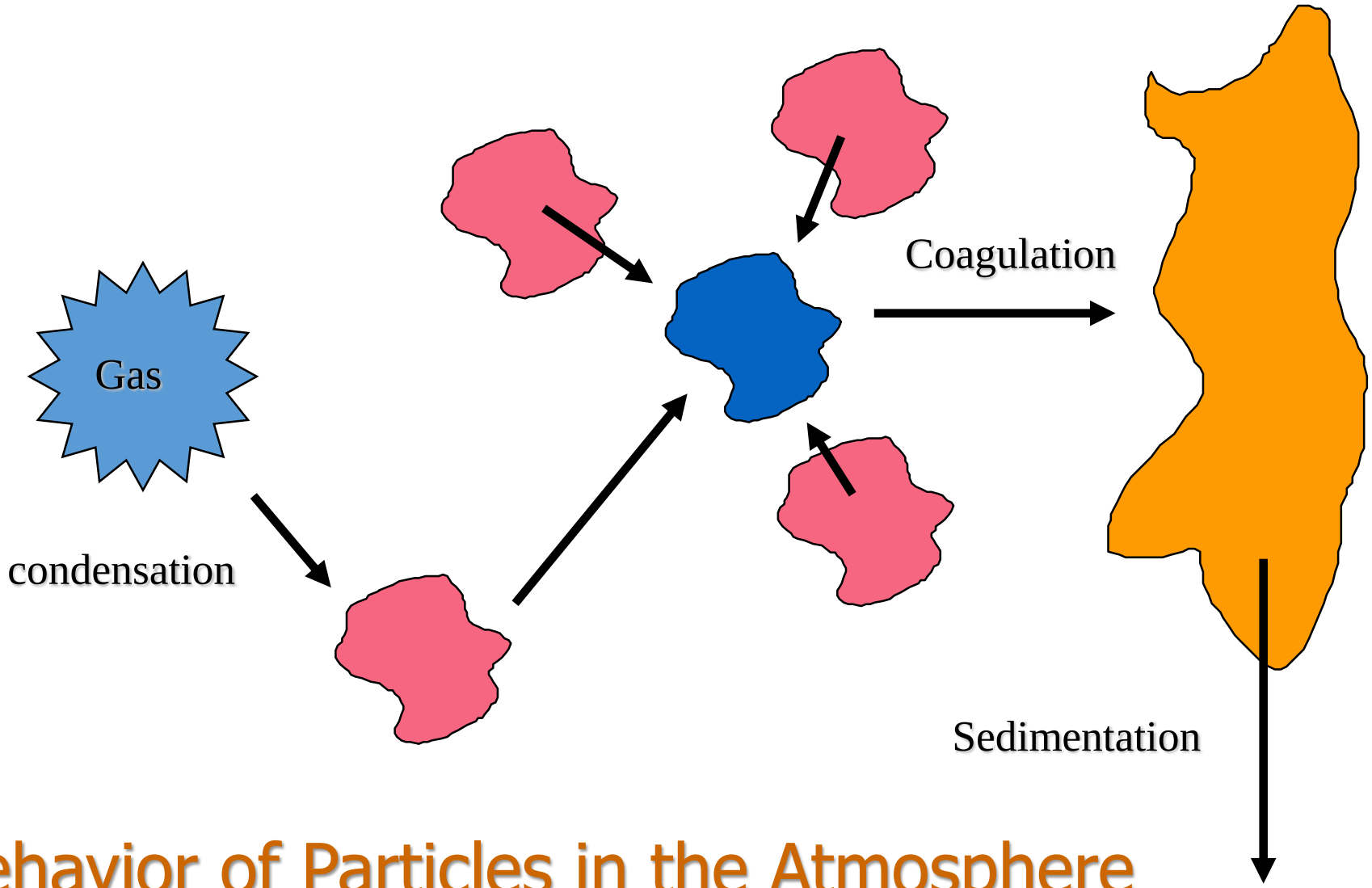
* For smaller particles, $u > V_t$

Suspending in the atmosphere for a long time.

* For larger particles, $u < V_t$

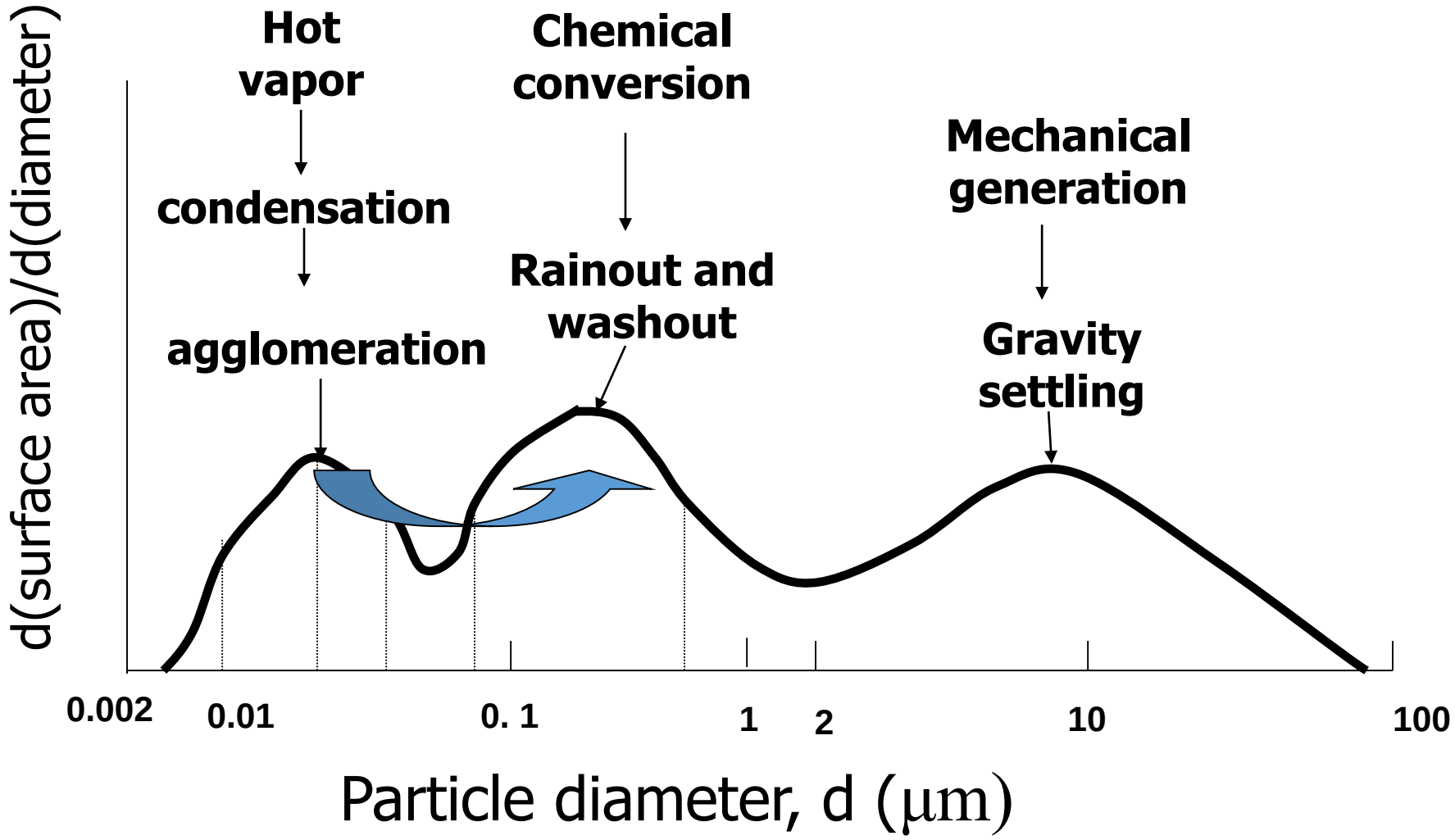
Particles will settle to the ground, not causing air pollution.

- Course or Mechanically generated particles 1-100 μm.
  - dust, sea spray, industrial grinding
  - removed by sedimentation



Behavior of Particles in the Atmosphere

Fig. 8.11 Behavior of Particles in the Atmosphere



BEHAVIOR OF PARTICLES IN ATMOSPHERE

- The first two peaks in **Fig. 8.11** represent almost exclusively **secondary particles**, formed in the atmosphere from gaseous precursors;

  - The gaseous precursors of secondary particles are primarily SO2, NOx, NH3, and hydrocarbons.

  - Ammonia (NH3) is widely distributed in the atmosphere, coming mostly from biological sources, rather than from human sources.

- the third peak represents for the most part **primary particles**, emitted to the atmosphere in particulate form.

BEHAVIOR OF PARTICLES IN THE ATMOSPHERE

Much of what we discussed in this chapter is illustrated by Fig. 8.11.

Finest particles

- Diameters 0.005 to 0.1 μm (micrometer or micron),
- Enter the atmosphere mostly by condensation of hot vapors from combustion sources.
- Over several hours, they grow, mostly by agglomeration onto each other:
  - Some of this agglomeration occurs in the gas phase, caused by Brownian motion (diffusion) bringing them into contact;
  - some occurs inside cloud or fog droplets.

BEHAVIOR OF PARTICLES IN THE ATMOSPHERE

Mid-sized particles

- Diameters are 0.1 to 1 μm (formed from fine ones)
- Partly by agglomeration of finer particles and
- Partly by chemical conversion of gases and vapors to particles in the atmosphere.
- These particles are large enough to be removed by
  - Rainout (capture by drops in clouds) or
  - Washout (capture by falling raindrops).
- Although they do grow by agglomeration to form larger particles:
  - This process is slow compared to rainout and washout.

BEHAVIOR OF PARTICLES IN THE ATMOSPHERE

Larger particles

- Diameters are 2 to 100 µm
- They are mechanically generated
- Some are derived from industrial sources
- Mostly removed by gravity settling:
  - With the action of clouds and rain
  - Without the action of clouds and rain.

Behavior of Particles in the Atmosphere

Size range	0.05~0.1μm	0.1~1μm	2~100μm
Production process	condensation	Chemical conversion	Mechanical generation
Types	secondary	secondary	primary
State	Liquid or tar	Liquid or tar	solid
Removal mechanism	agglomeration	Rainout and washout	Gravity settling
Example	Tobacco smoke	Exhaust gases	Coal dust

Figure 8.12 summarizes this chapter:

Truck hauling sand down the road:

1. Sand blows off the truck and falls to the ground causing local nuisance.
2. Truck stirs up road dust & generates tire wear particles that are *local air pollutants (do not remain long in the atmosphere).*
3. Truck's exhaust contains fine particles generated by combustion; remain in the atmosphere for several days and contribute to the *regional fine particulate problem.*

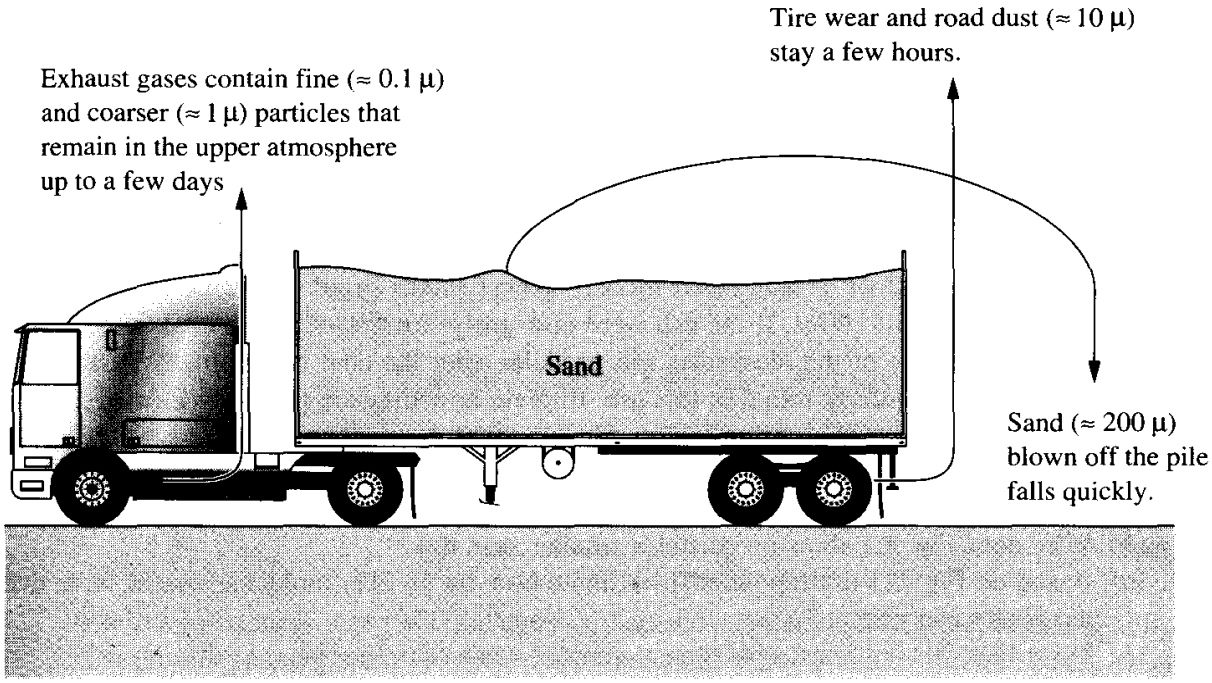


FIGURE 8.12
A truck, loaded with sand, puts three different sizes of particles into the atmosphere.

SUMMARY

1. The particles of air pollution interest are mostly in the size range 0.01 to 10 μ

2. Fine particles in the atmosphere are largely *secondary particles*, formed the atmosphere from gaseous precursors.

3. Most coarser particles in the atmosphere are *primary particles*, which enter the atmosphere as particles.

4. Most particles of air pollution interest are in the size range where the Stokes' equation for the drag force on the particle *can be used* with satisfactory accuracy.

5. Because particles of air pollution interest are rarely present in the air or in a gas stream as a uniform particle size set, we normally have to deal with the *distribution of particle sizes*.

SUMMARY

6. Particles smaller than about 2 μ have the following properties:
   - primarily produced by condensation or chemical reaction of gases or vapors
   - behave quite differently from the particles with which we are familiar (like sand and gravel).
   - their high surface area per unit mass makes them adhere to one another if they are brought into contact.