Health Effects of Air Pollution

For extra reference: EPA

http://www.epa.gov/air/urbanair/

Criteria Air Pollutants

- Gases: O_3, CO, NO_x, So_x
- Particles: PM2.5, Pb
  - NAAQS from US Federal Clean Air Act
    - Primary standards: protect public health, including "sensitive" populations
    - Secondary standards: protect public welfare Hazardous Air Pollutants: Hg, dioxins, etc
  - Regulated under 1990 CAA Amendments
- Some other important health aspects
  - Bioaerosols, medicinal purposes

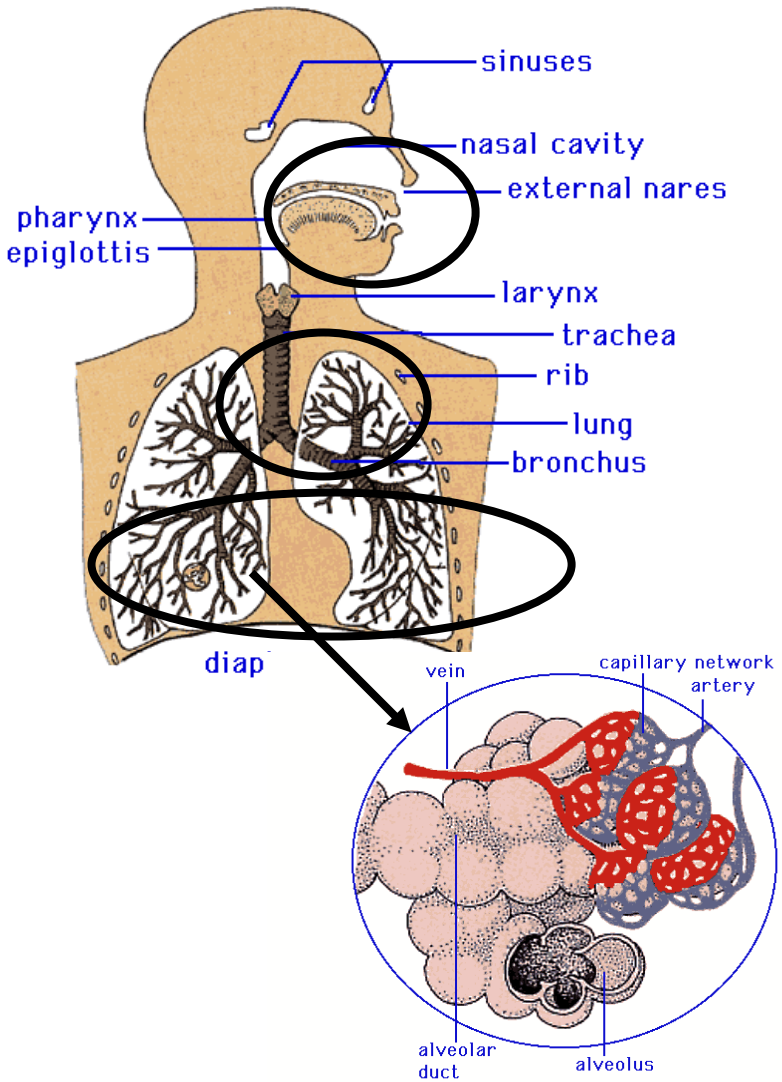
Exposure to Air Pollutants

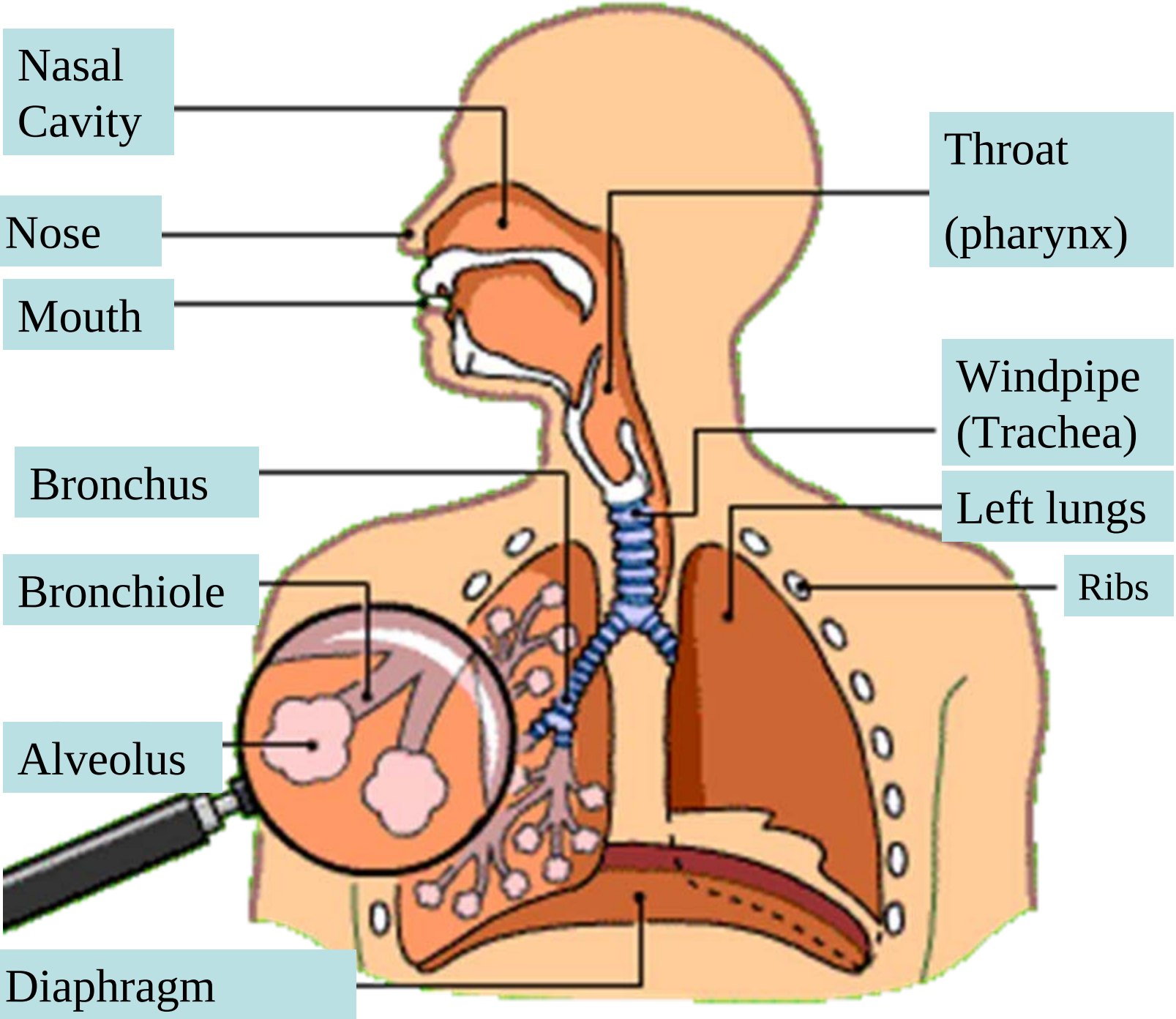
- Chronic
- Acute
  - Air Pollution Episode – short-term increase concentrations
- Dependent on local conditions
- Epidemiological studies
  - Statistical relationship between environmental factors and human disease
  - Population susceptibility or change
  - Latency period
    - Lung cancer – up to 30 years
- Toxicological studies
  - Determine effects of toxic substances
- Pollutant interactions

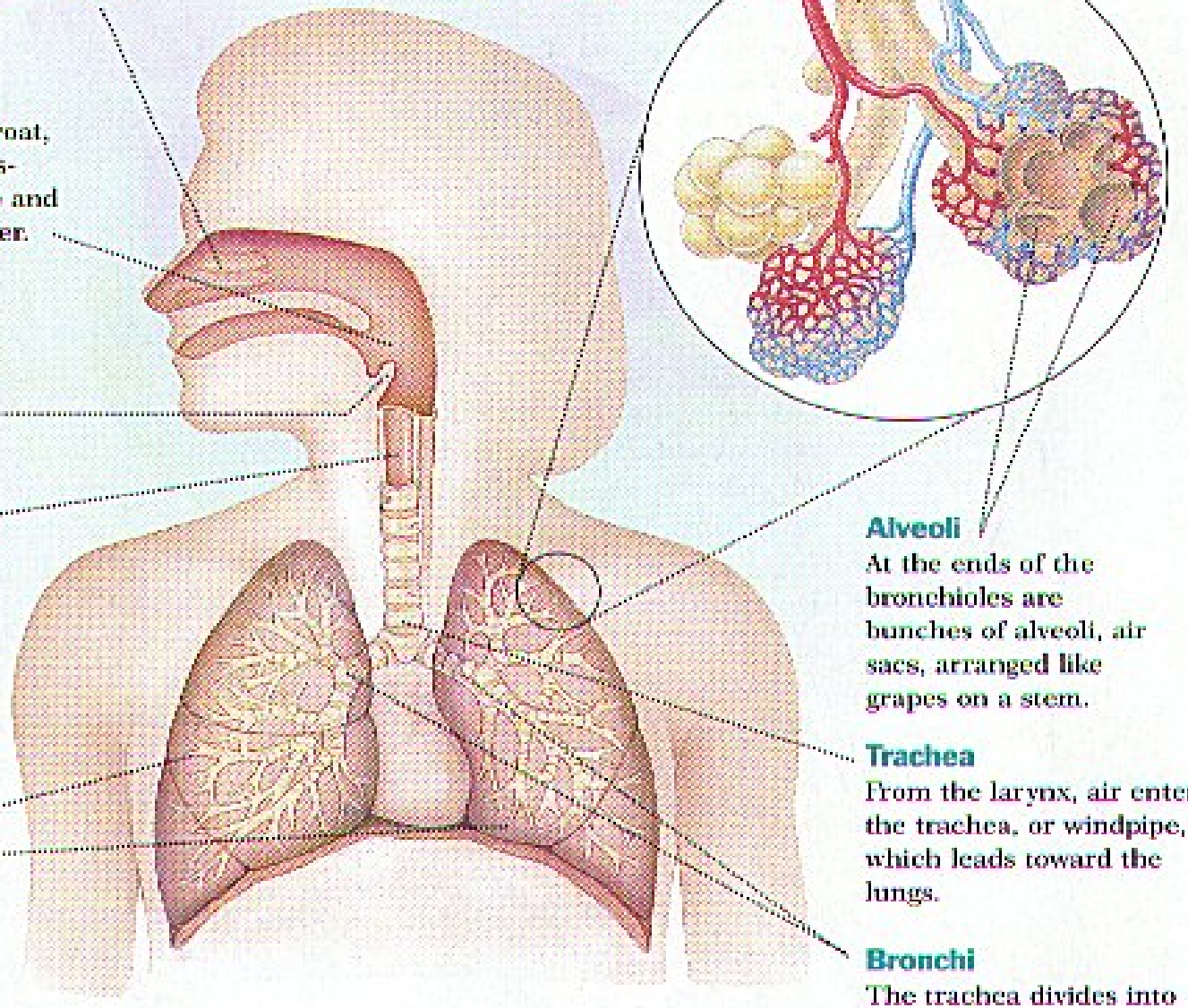
Smog Episode in New York City, 1963
National Archives, photo by Chester Higgins

Respiratory System

- **Pollutants transported in via inhalation-respiratory tracts**
- **Person at rest breathes 12 to 15 times a minute (10 liters/min)**
- **3 parts of respiratory system**
  - Naso-pharyngeal (HAR)
  - Tracheo-bronchial (TBR)
  - Pulmonary-Alveolar (GER)
- **Lungs serve as portal of entr**
  - Highly permeable and lots of blood flow
  - Pulmonary-Alveolar Surface Area > 75 m^2




Nasal Cavity
Nose
Mouth
Throat (pharynx)
Windpipe (Trachea)
Bronchus
Left lungs
Bronchiole
Ribs
Alveolus
Diaphragm



Nasal cavity
Air passing over the mucous membrane of the nasal cavity is moistened, warmed, and filtered.

Bronchiole
Inside the lungs, the bronchi branch into smaller tubes called the bronchioles.

Pharynx
The pharynx, or throat, is located where passages from the nose and mouth come together.

Epiglottis
The epiglottis is a flap of elastic tissue that forms a lid over the opening to the trachea.

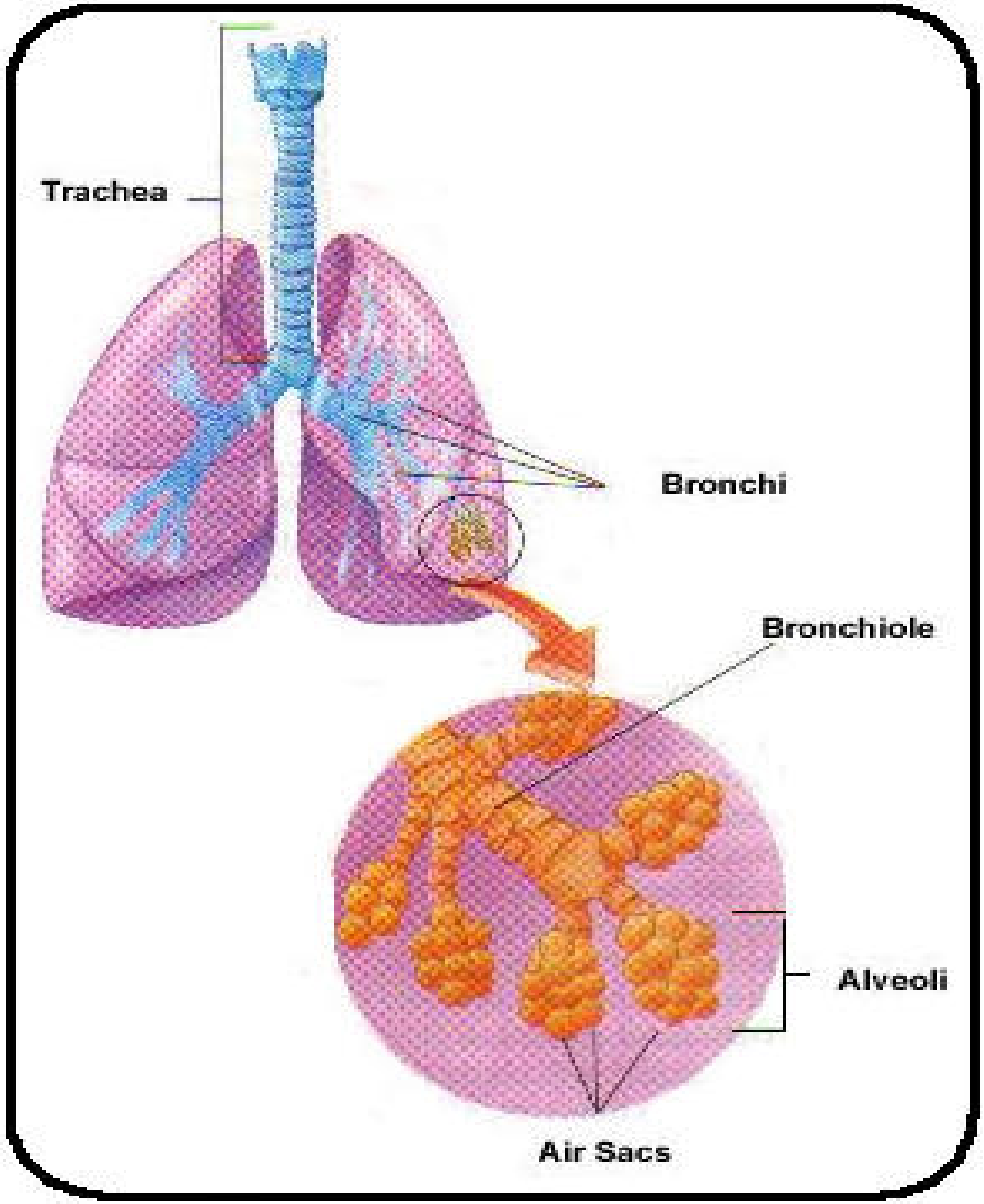
Larynx
The larynx, or voice box, is located between the pharynx and the trachea. It contains two ligaments—the vocal cords—that produce sound when air moves through them.

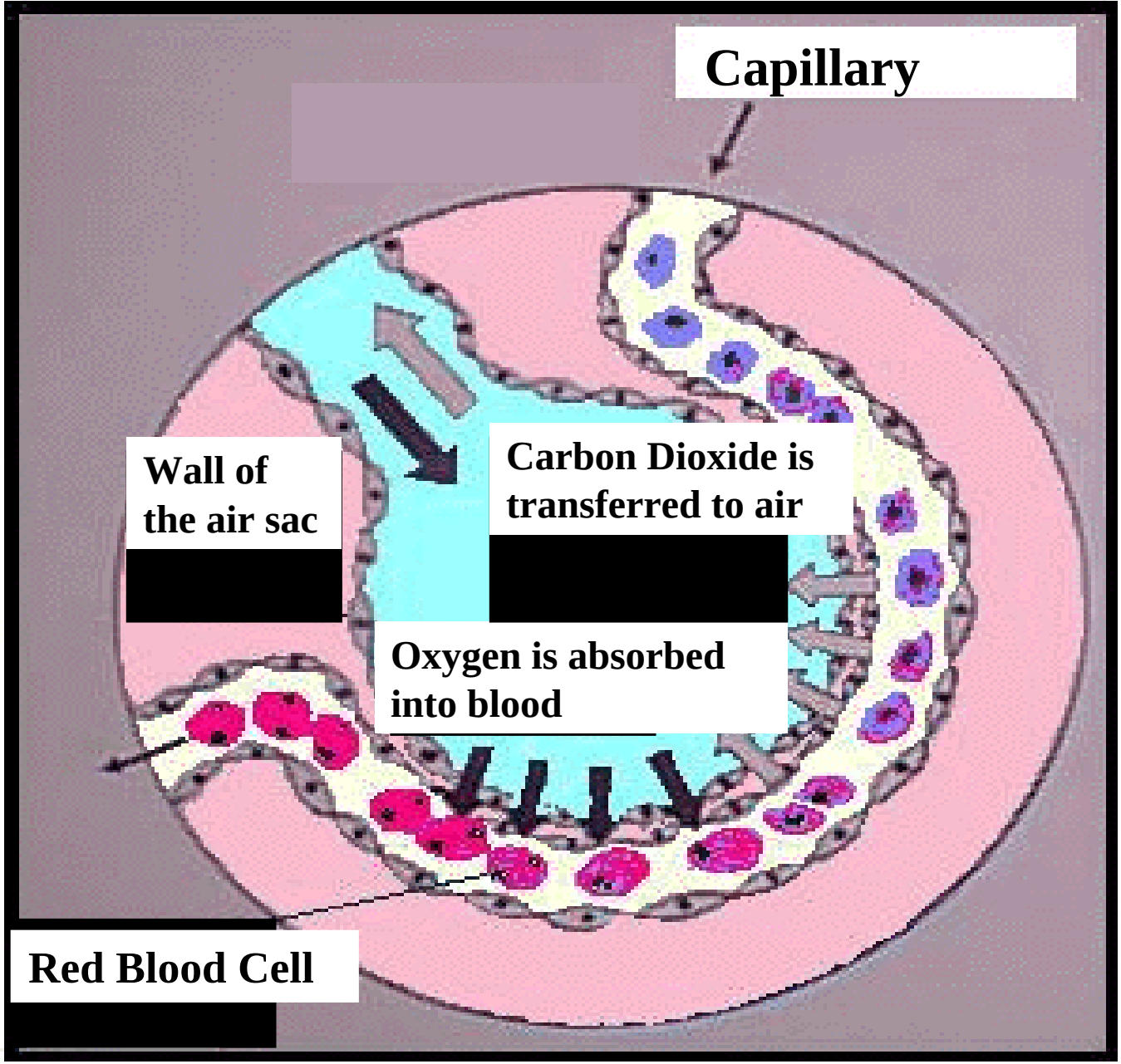
Lungs
If one lobe is injured or diseased, the other lobes may be able to function normally.

Alveoli
At the ends of the bronchioles are bunches of alveoli, air sacs, arranged like grapes on a stem.

Trachea
From the larynx, air enters the trachea, or windpipe, which leads toward the lungs.

Bronchi
The trachea divides into two tubes called bronchi.


Trachea
Bronchi
Bronchiole
Alveoli
Air Sacs


Capillary
Wall of the air sac
Carbon Dioxide is transferred to air
Oxygen is absorbed into blood
Red Blood Cell

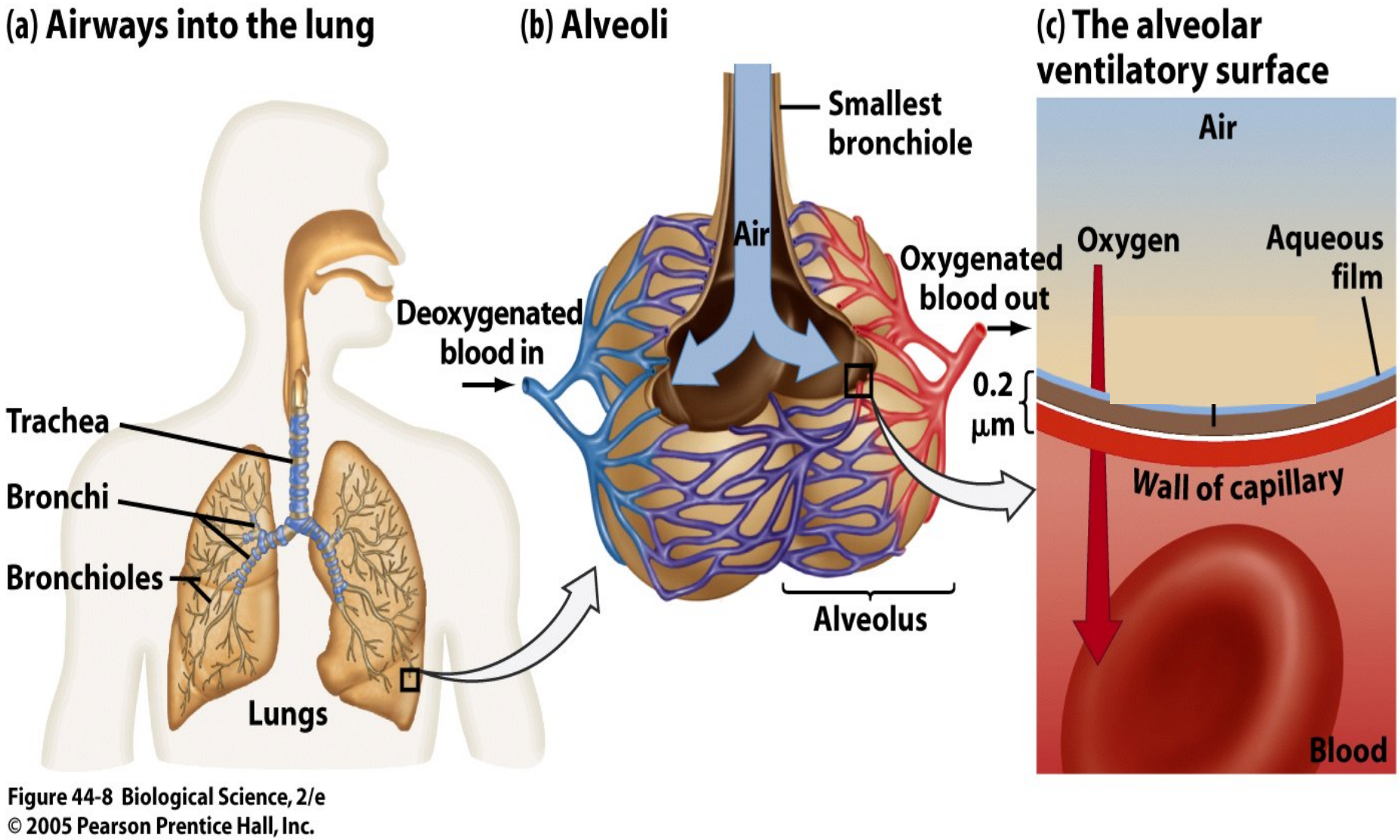
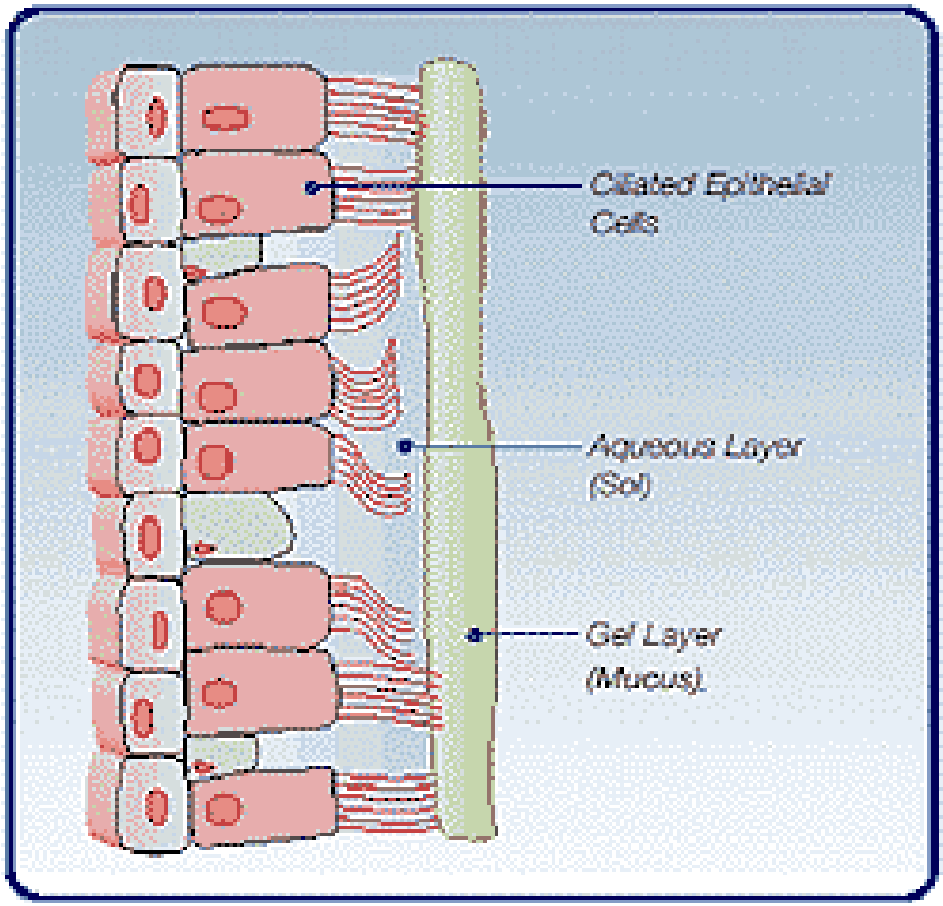


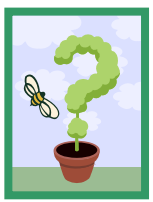
Figure 44-8 Biological Science, 2/e

Small aerosol particles can penetrate through the alveoli wall

Respiratory System



- Natural protection mechanisms (for particles)
- Naso-pharyngeal (HAR)
  - Nose hairs (filter particles)
  - Cough, Sneeze
  - Mouth breathing vs nasal breathing
- Tracheo-bronchial (TBR)
  - Mucociliary "escalator"
  - Bronchial constriction
- Pulmonary-Alveolar (GER)
  - Macrophages (phagocytosis)
  - No cilia in Alveoli



Question: Do the natural protection mechanisms protect against toxic gases such as CO, O_3, SO_2?

Respiratory Particle Cleaning Mechanisms

Clearance Mechanism	Site Cleaned	Rate of Cleaning
Cough	Trachea, brochus	Instantaneous
Ciliary	Large Bronchi bronchiole tree Bronchiole airways	0.5 hr 3 hrs 6 hrs
macrophages	Alveoli (air sacs)	24 hrs
lymphatics	Lung tissue	Months,years

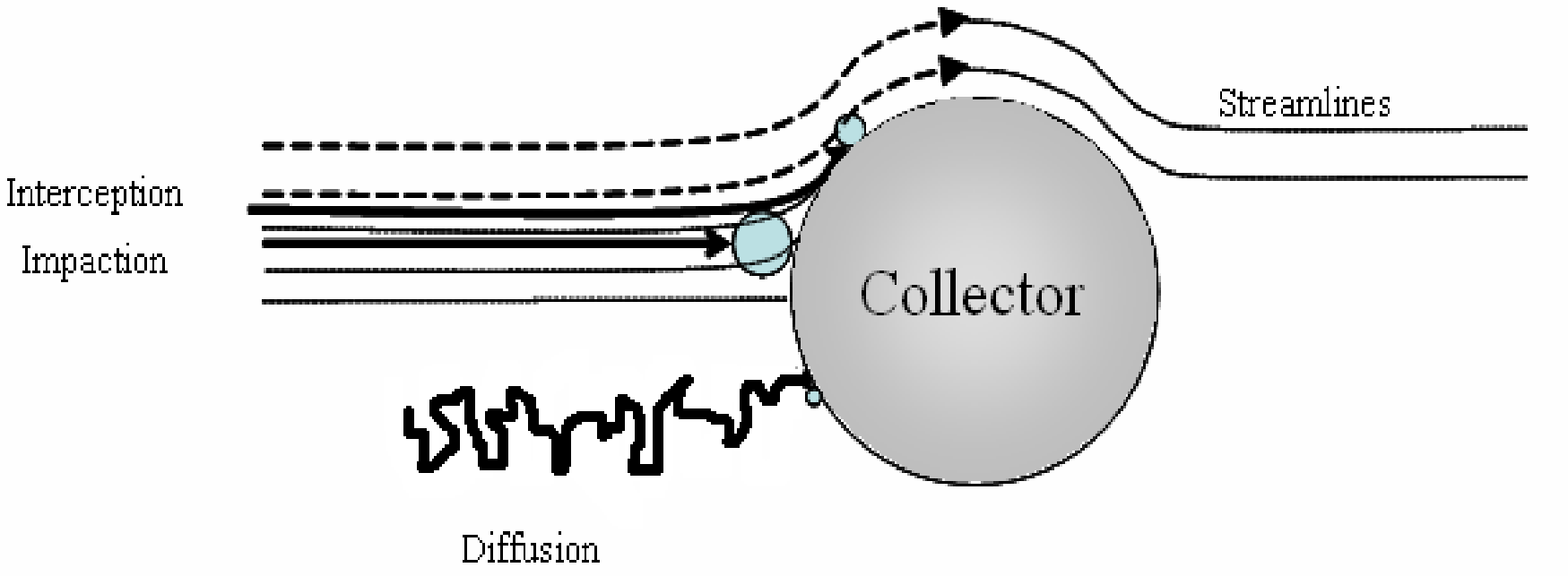
Criteria Air Pollutants: Particulate Matter PM

- Small solid/liquid aerosol particles that remain suspended in air
- Causes: materials handling, combustion processes, gas conversion reactions
- Main sources: industrial processes, coal and oil burning, diesel motor vehicles

Pollutant	Primary Stds. (human health)	Averaging Times	Secondary Stds.
Particulate Matter (PM_{10})	*Replaced with PM 2.5*	Annual (Arith. Mean)	
	150 $\mu g/m^3$	24-hour	
Particulate Matter ($PM_{2.5}$)	15.0 $\mu g/m^3$	Annual (Arith. Mean)	Same as Primary
	35 $\mu g/m^3$	24-hour	

Criteria Air Pollutants: Particulate Matter

- Following inhalation: two possible fates
  - Deposition or Exhalation
- Particle Fate depends upon:
  - Aerodynamic & physiological behavior (human being)
- Methods of Particle Deposition
  - Interception, Inertial Impaction, Brownian Diffusion, Electrostatic Attraction, Gravitational Settling

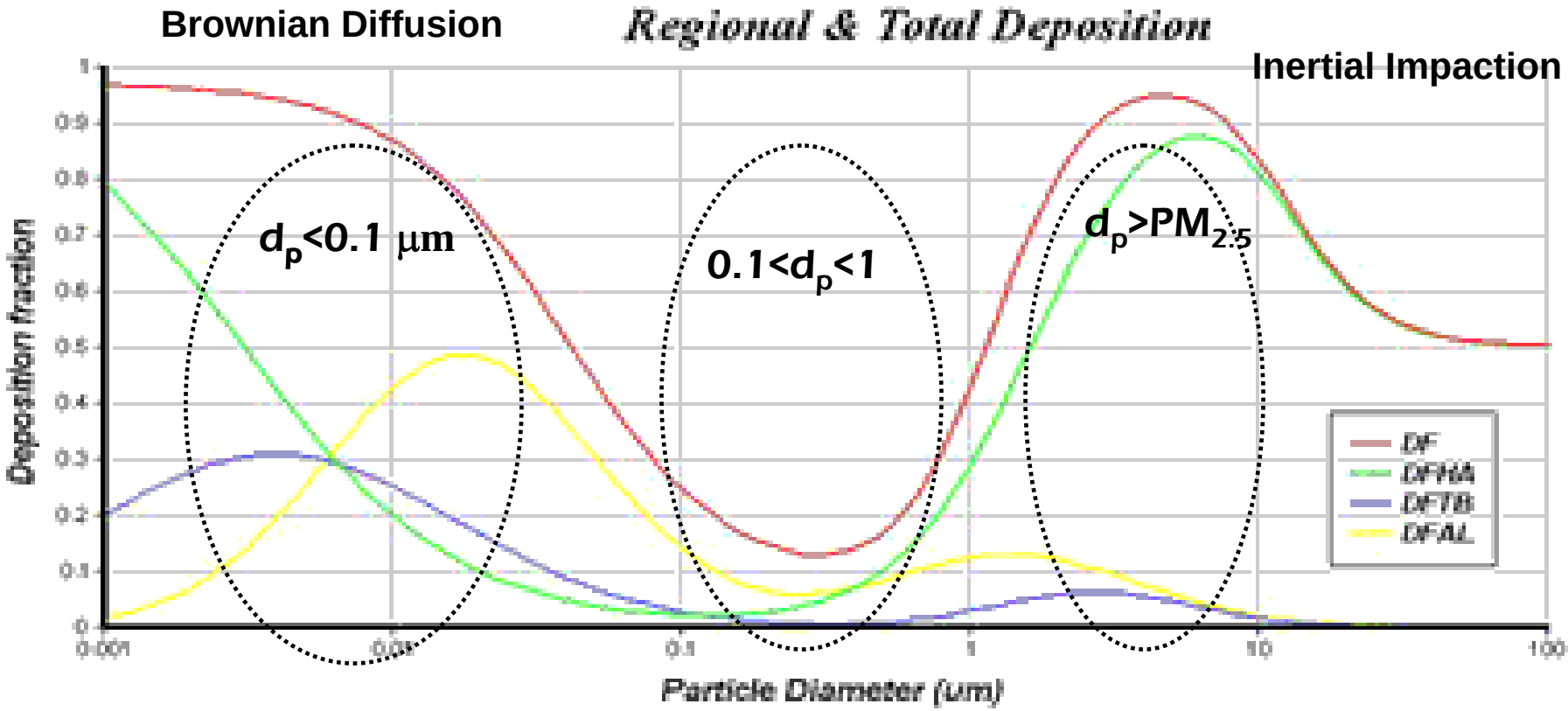


Criteria Air Pollutants: Particulate Matter

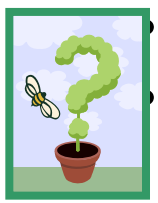
- Deposition Mechanisms
  - Inertial Impaction
    - Predominant for $d_p \geq 3$ μm
      $\rightarrow PM_{2.5}$ regulations
    - Primarily in Naso-pharyngeal or Tracheo-bronchial regions
  - Brownian diffusion
    - Predominant for $d_p \leq 0.5$ μm
    - Primarily in Pulmonary-Alveolar region
  - Gravitational Settling
    - 3-5 μm ($V_{TS} \propto d_{ar}^2$)
    - Distal regions of bronchial airways
- Minimal Mechanisms
  - Electrostatic Attraction
  - Interception
    - Elongated particles such as fibers

Particulate Matter

DF=Total
DFHA=Head Airways
DFTB=Tracheobronchial
DFAL=Alveolar region



- Why is there a dip in particle deposition between 0.1 and 1 μm?
- Assume this is for nasal breathing.
- How might this graph change for mouth breathing?



Criteria Air Pollutants: Particulate Matter

- Wheezing & coughing to heart attacks and death
- TSP (Total Suspended Particles)
  - In presence of SO_2, direct correlation between TSP and hospital visits for bronchitis, asthma, emphysema, pneumonia, and cardiac disease
  - Studies suggest ~60,000 deaths from PM
  - 1% increase in mortality for10 $\mu g/m^3$ increase in PM
    - Respiratory mortality up 3.4% for the same
      Cardiovascular mortality up 1.4% for the same

Criteria Air Pollutants: Particulate Matter

- PM_{10} d_p <10 μm, coarse (2.5-10 μm) & fine particles
  - Particles > 10 μm mostly deposited in nasal-pharangycal
- $PM_{2.5}$ (<2.5 μm, fine particles)
  - Serious health effects in alveolar/gas exchange region

    → shift in EPA regulation changed PM_{10} to $PM_{2.5}$

  Toxic or Carcinogenic – pesticides, lead, arsenic, radioactive material

  8% Increase in lung cancer for each 10 μg/m³ increase in $PM_{2.5}$

Criteria Air Pollutant: Particulate Matter

- Asthma
  - 14 Americans die/day of asthma
    (3 times greater than 20 yrs ago)
  - More medicine, more doctor & hospital visits
    → more health care costs
- Particulate episodes in presence of SO_2 ("Killer Smogs")
  - 1930: Meuse Valley in Belgium – 60 deaths
  - 1948: Donora, Pennsylvania - 20 deaths
  - 1952: "Lethal London Smog"- 12,000 deaths

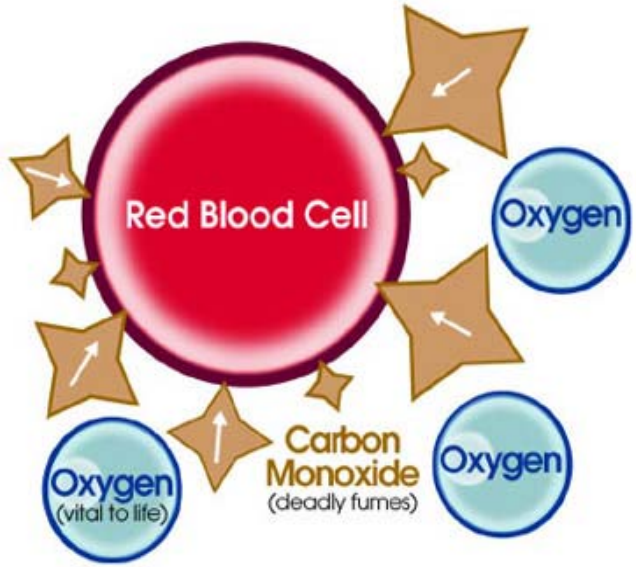
Criteria Air Pollutants: Carbon Monoxide CO

- Colorless, odorless, tasteless gas→ "Silent Killer"
  - Cause: incomplete combustion of carbon based fuels
  - Source: transportation sector, residential heating units
  - NAAQS regulates CO in outdoor air
- OSHA (50 ppm CO averaged over 8-hour period)

Pollutant	Primary Stds.	Averaging Times	Secondary Stds.
Carbon Monoxide	9 ppm (10 milligram/m^3)	8-hour	None
	35 ppm (40 milligrams/m^3)	1-hour	None

Criteria Air Pollutants: Carbon Monoxide CO

- Reacts with blood hemoglobin
  - Forms carboxyhemoglobin (HbCO) rather than oxyhemoglobin (HbO_2)
  - Prevents oxygen transfer
- Toxic effects on humans
  - Low-level: cardiovascular & neurobehavior
  - Headaches/nausea/fatigue/ *death*
  - Oxygen deficient to vulnerable people (anemia, chronic heart or lung disease, high altitude residents, smokers)
    - Cigarette smoke: 400-450 ppm; smoker's blood 5-10% HbCO vs 2% for non-smoker



Criteria Air Pollutants: Carbon Monoxide CO

- Concern in homes
  - Install CO monitor
- No indoor CO regulations
  - >70 ppm → flu-like symptoms (w/out fever)
  - 150-200 ppm → disorientation, drowsiness, vomiting
  - >300 ppm → unconsciousness, brain damage, death
  - 500 Americans die/year from unintentional CO poisoning
- Treatment: fresh air, oxygen therapy, hyperbaric chamber

Criteria Air Pollutants: Ozone O_3

- Cause: atmospheric photochemical reaction
- Reactants: Hydrocarbons & Nitrogen Oxides
- NAAQS .08 ppm or 80 ppb 8 hr average
  .12 ppm or 120 ppb 1 hr average
- Acute Health effects
  - Severe ear/nose/throat irritation
  - Eye irritation at 100 ppb ozone
  - Interferes with lung functions
    - Coughing at 2 ppm ozone
- Chronic Health Effects
  - Irreversible, accelerated lung damage
  - Why do we use ozone as disinfectant for water and wastewater treatment?

Criteria Air Pollutants: Nitrogen Oxides NO_x

- Cause: Fuel combustion at high temps
- Source: mobile & stationary combustion sources
- Prolonged exposure $\rightarrow$ pulmonary fibrosis, emphysema, and higher lower respiratory tract illness in children
- NAAQS = Annual Average 0.053 ppm as NO_2
- Toxic effects at 10-30 ppm NOx
  - Nose and eye irritation
  - Lung tissue damage
    - Pulmonary edema (swelling)
    - Bronchitis
    - Defense mechanisms
  - Pneumonia
  - Aggravate existing heart disease

Criteria Air Pollutants: Sulfur Oxides SO_x

- Cause: Burning fuel that contains sulfur
- Source: Electric power generation, diesel trucks
- Gas and particulate phase
- Soluble and absorbed by respiratory system
- NAAQS = 0.14 ppm 24 hr average
- Short-term intermittent exposures
  - Broncho-constriction (temporary breathing difficulty)
  - Ear/Nose/Throat irritation
  - Mucus secretion
- Long-term exposures
  - Respiratory illness
  - Aggravates existing heart disease
- Intensified in presence of Particulate Matter
  - London "Killer" Smog health effects were combination of the two air pollutants (SOx and aerosol particles)

Criteria Air Pollutants: Lead (Pb)

- Source: burning fuels that contain lead (phased out), metal processing, waste incinerators, lead smelters, lead paint
- Absorbed into blood; similar to calcium
- NAAQS = 1.5 μg/m³ Pb Quarterly Average
- **Kellog Idaho Lead smelter emissions caused children in region to have lower IQ and brain effects (UW CEE grad was EPA engineer in charge of cleanup at this site).**
- Accumulates in blood, bones, muscles, fat
  - Damages organs – kidneys, liver, brain, reproductive system, bones (osteoporosis)
  - Brain and nervous system – seizures, mental retardation, behavioral disorders, memory problems, mood changes,
    - Young children - lower IQ, learning disabilities
  - Heart and blood – high blood pressure and increased heart disease
  - Chronic poisoning possible

Criteria Air Pollutants: Air Quality Index (AQI)

- **EPA AQI is for reporting daily air quality. The AQI focuses on short term health effects (1-48 hr after exposure). AQI is calculated from concentrations of SO_2, CO, O_3, and particles.**
- **AQI values in the 0-50 indicates Good air quality.**
- **AQI in the 51-100 range indicates Moderate air quality and exposures will cause short term health effects to some sensitive people (*and unhealthy effects for long-term exposure for most people*).**
- **Pilat opinion is that "Moderate" air quality is not very healthy. The SO_2, PM, and O_3 NAAQS standards are set at levels with proven damaging health effects with little or no margin of safety; the CO NAAQS standard has a margin of safety.**

Criteria Air Pollutants: Air Quality Index (AQI)

- AQI is the highest magnitude of the PM, SO_2, CO, and O_3 individual Index values

AQI Value	Air Quality	24 hr PM2.5 ($\mu g/m^3$)	24 hr SO_2 (ppm)	8 hr CO (ppm)	8 hr O_3 (ppm)
0-50	Good	0-15.4	0.0 - .034	0.0-4.4	.000-.064
51-100	Moderate	15.5-40.4	.035-.144	4.5-9.4	.065-.084
101-150	Unhealthy to Sensitive	40.5-65.4	.145-.224	9.5-12.4	.085-.104
151-200	Unhealthy	65.5-150.4	.225-.304	12.5-15.4	.105-.124
201-300	Very Unhealthy	150.5-250.4	.305-.604	15.5-30.4	.125-.374
NAAQS		35 $\mu g/m^3$	0.14 ppm	9 ppm	.08 ppm

http://airnow.gov.index.cfm?action=aqiconc_aqi_calc

- **Equation for Calculating an Air Pollutant AQI Index Value**

$$I_P = \left(\frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} \right) \left[Cp - BP_{Lo} \right] + I_{Lo}$$

Ip = Index magnitude for air pollutant P

Cp = concentrat ion for pollutant P

I_{Hi} = AQI value correspond ing to BP_{Hi}

I_{Lo} = AQI value correspond ing to BP_{Lo}

BP_{Hi} = breakpoint that is greater than Cp

BP_{Lo} = breakpoint that is less than Cp

Calculate the AQ Index of air that contains 0.077 O_3 (8 hr average), 8.4 ppm CO (8-hr average), & 54.4 μg/m³ PM 2.5 Particles (24-hour average)

$$I_{ozone} = \left(\frac{100 - 51}{0.084 - .065 \text{ ppm}} \right) [.077 - .065 \text{ ppm}] + 51 = 82$$

$$I_{CO} = \left(\frac{100 - 51}{9.4 - 4.5 \text{ ppm}} \right) [8.4 - 4.5 \text{ ppm}] + 51 = 90$$

$$I_{PM2.5} = \left(\frac{150 - 101}{65.4 - 40.5} \right) [54.4 - 40.5] + 101 = 128$$

The index calculated for the air pollutant PM2.5 is the highest magnitude so the Air Quality Index = 128

http://www.k12science.org/curriculum/airproj/whataqi.html

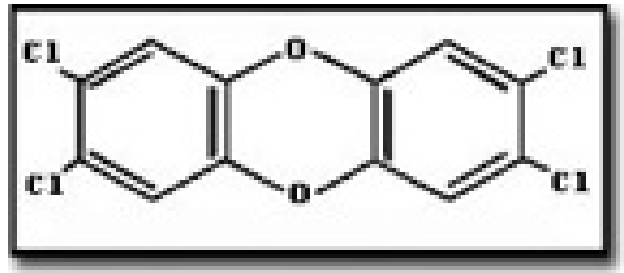
Hazardous Air Pollutant HAP: Mercury Hg

- Elemental Hg inhaled as a vapor, absorbed by lungs
- Cause: vaporized mercury
- Sources: coal combustion, accidental spill, mining (*teeth silver fillings*)
- Effects: Nervous system (acute, high), respiratory system (chronic, low), kidneys, skin, eyes, immune system; Mutagenic properties
- Symptoms
  - Acute: chills, nausea, chest pains/tightness, cough, gingivitis, general malaise
  - Chronic: weakness, fatigue, weight loss, tremor, behavioral changes

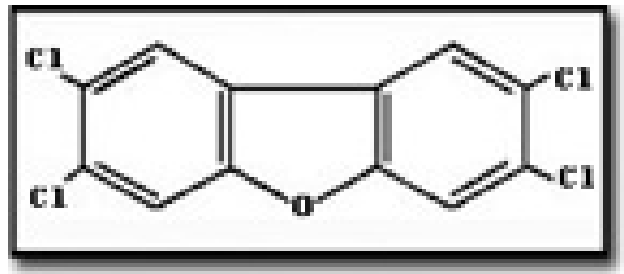
istockphoto.com
http://www.istockphoto.com/imageindex/728/1/728179/Mercury_drops_Hg.html

Hazardous Air Pollutant Dioxins

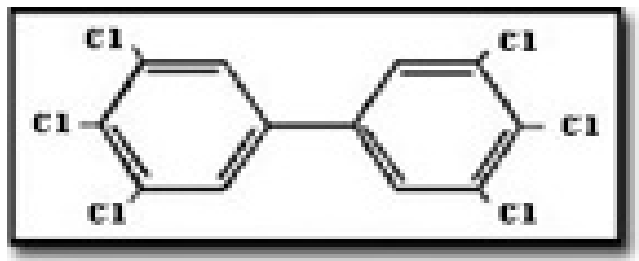
- Generic term for several chemicals that are highly persistent in the environment
  - chlorinated dibenzo-p-dioxins (CDDs)
  - chlorinated dibenzofurans (CDFs)
  - certain polychlorinated biphenyls (PCBs)
- Cause: burning hydrocarbons in presence of chlorine or chlorides
- Sources: waste incinerators
- Notice the Chlorine atoms on the benzene ring type molecules (probably all these type compounds are carcinogenic)
- Does using Chlorine to treat drinking water result in the formation of carcinogenic compounds?



2,3,7,8-Tetrachlorodibenzo-p-dioxin



2,3,7,8-Tetrachlorodibenzofuran



3,3',4,4',5,5'-Hexachlorobiphenyl

Hazardous Air Pollutant: Dioxins

Comparative Photos Showing Ukraine's Viktor Yushchenko Immediately Prior To And Immediately Following Dioxin Poisoning

http://en.wikipedia.org/wiki/Viktor_Yushchenko

(Note: this is an extreme case of dioxin poisoning)

- Varying toxicity
  - Problems with high exposures
  - Exact effects of low exposures not known
- Health Effects
  - Carcinogenic
    - Some are "known human carcinogen" (2,3,7,8 tetrachlordibenzo-p-dioxin, TCDD)
    - Other dioxins are "reasonably anticipated to be a Human Carcinogen"
  - Reproductive and developmental effects
  - Chloracne

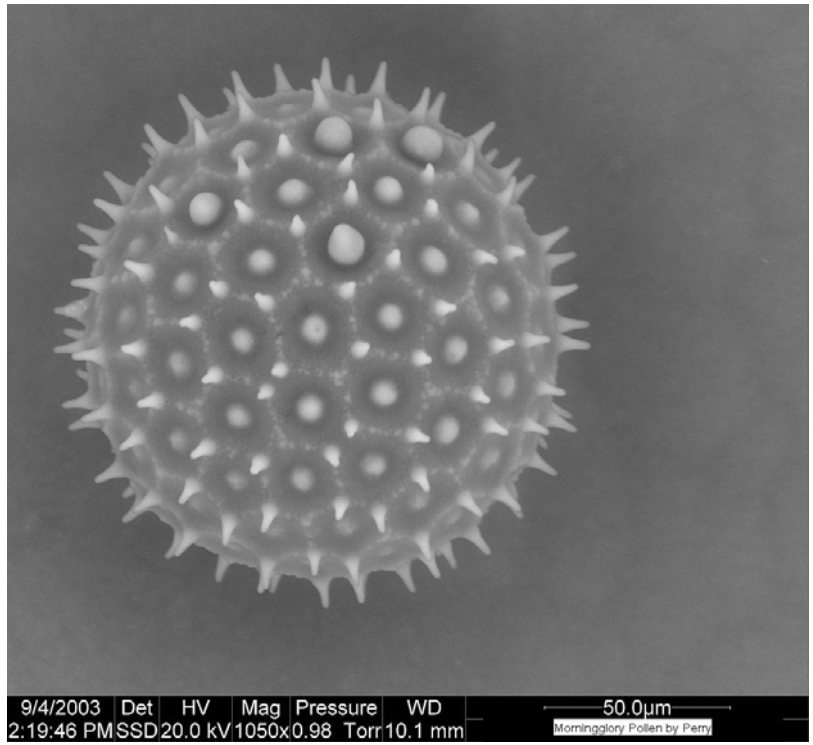
Other Aerosols: Bioaerosols

Mechanical aeration at
Waste water treatment plant

- Aerosols with organic origin
  - Non-viable: pollen, dander, insect excreta, sea salt
  - Viable: microorganisms
- Cause: aerosolization of organic materials
- Sources:
  - Human: sneezing, coughing
  - wind, waves, Waste water treatment plants,cooling towers
- Health Effects: allergies (pollen) to death (pathogenic organisms)
  - Pathogenic – Minimum Infectious Dose

Other Aerosols: Bioaerosols

- Allergies
  - Pollen, dander, fungi (spores)
- Airborne transmission of disease
  - Bird flu, SARS, Legionnella (pneumonia)
  - Indoor Air Quality
    - Ventilation Systems – moist ductwork, protection, recycled air
    - Office Buildings – Sick Building Syndrome
      - Hospital (nosocomial)
    - Biological Warfare
      - Anthrax, Ebola virus



Morning Glory Pollen SEM

University of West GA Microscopy Center

http://www.westga.edu/~geosci/wgmc/plants_pics.htm

Other Aerosols: Medicinal Applications

- Purposely applied medicine
- Take advantage of lung's large surface area of the thin membrane of alveolar air sacs through which aerosol particles (especially liquid solutions) easily pass into the blood.
- Asthma
  - Inhaler
- Diabetes
  - Pfizer uses Insulin