Updated: 11 December 2019

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CEE 370 Environmental Engineering Principles

Lecture #36

Air Pollution I:

Air Quality & Pollutants

Reading: Mihelcic & Zimmerman, Chapt 11

Reading: Davis & Cornwall, Chapt 7-1 to 7-5

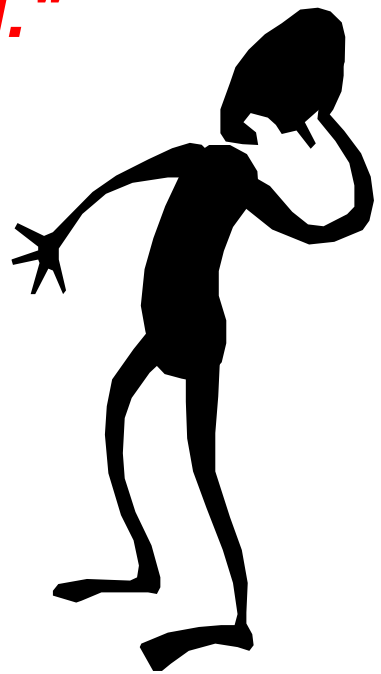
Reading: Davis & Masten, Chapter 12-1 to 12-5

Air Pollution and Control

- Regulations
- Meteorology and Climatology
- Acidic Pollutants
- Particulate Pollutants
- Stratospheric Ozone Destruction
  - Effects of CFCs
- Greenhouse Pollutants
  - Global Warming
- Tropospheric Photochemical Pollutants
- Hazardous Pollutants
- Indoor Air Pollution

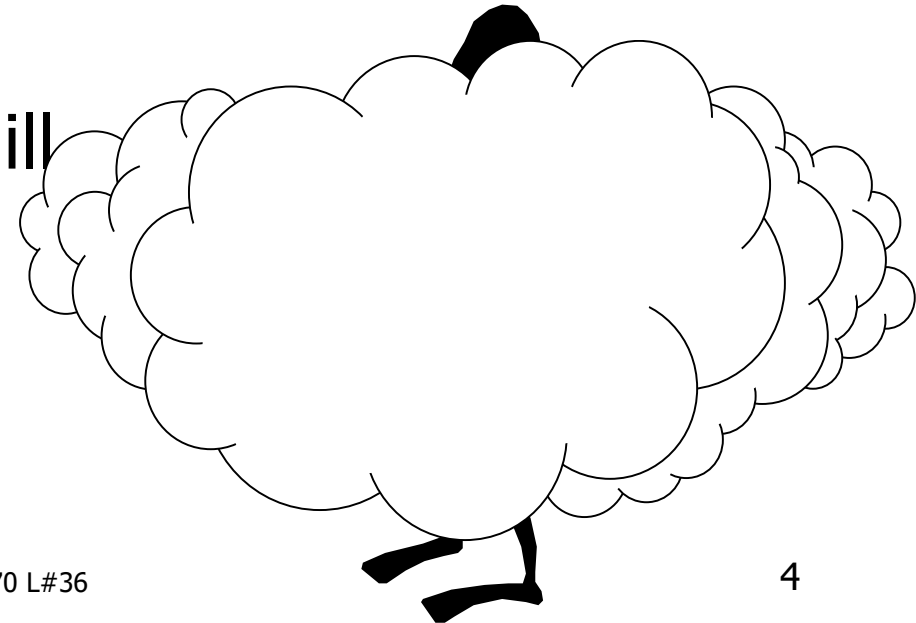
". . . whosoever shall be found guilty of burning coal shall suffer the loss of his head."

King Edward II, circa 1300 a.d.



Some well known events

- 1931: Manchester, England
  - 500 dead
  - particulates & acids
- 1948: Donora, PA
  - 20 dead
  - several thousand ill



Events, cont.

TABLE 11–3 Three Major Air Pollution Episodes

	Meuse Valley, Belgium, 1930 (Oct. 1–5)	Donora, Pennsylvania, 1948 (Oct. 2–31)	London, 1952 (Dec. 5–9)
Population	No data	12,300	8,000,000
Weather	Anticyclone, inversion, and fog	Anticyclone, invasion, and fog	Anticyclone, inversion, and fog
Topography	River valley	River valley	River plain
Most probable source of pollutants	Industry (including steel and zinc plants)	Industry (including steel and zinc plants)	Household coal-burning
Nature of the illnesses	Chemical irritation of exposed membranous surfaces	Chemical irritation of exposed membranous surfaces	Chemical irritation of exposed membranous surfaces
Number of deaths	63	17	4000
Time of deaths	Began after second day of episode	Began after second day of episode	Began on first day of episode
Suspected proximate cause of irritation	Sulfur oxides with particulates	Sulfur oxides with particulates	Sulfur oxides with particulates

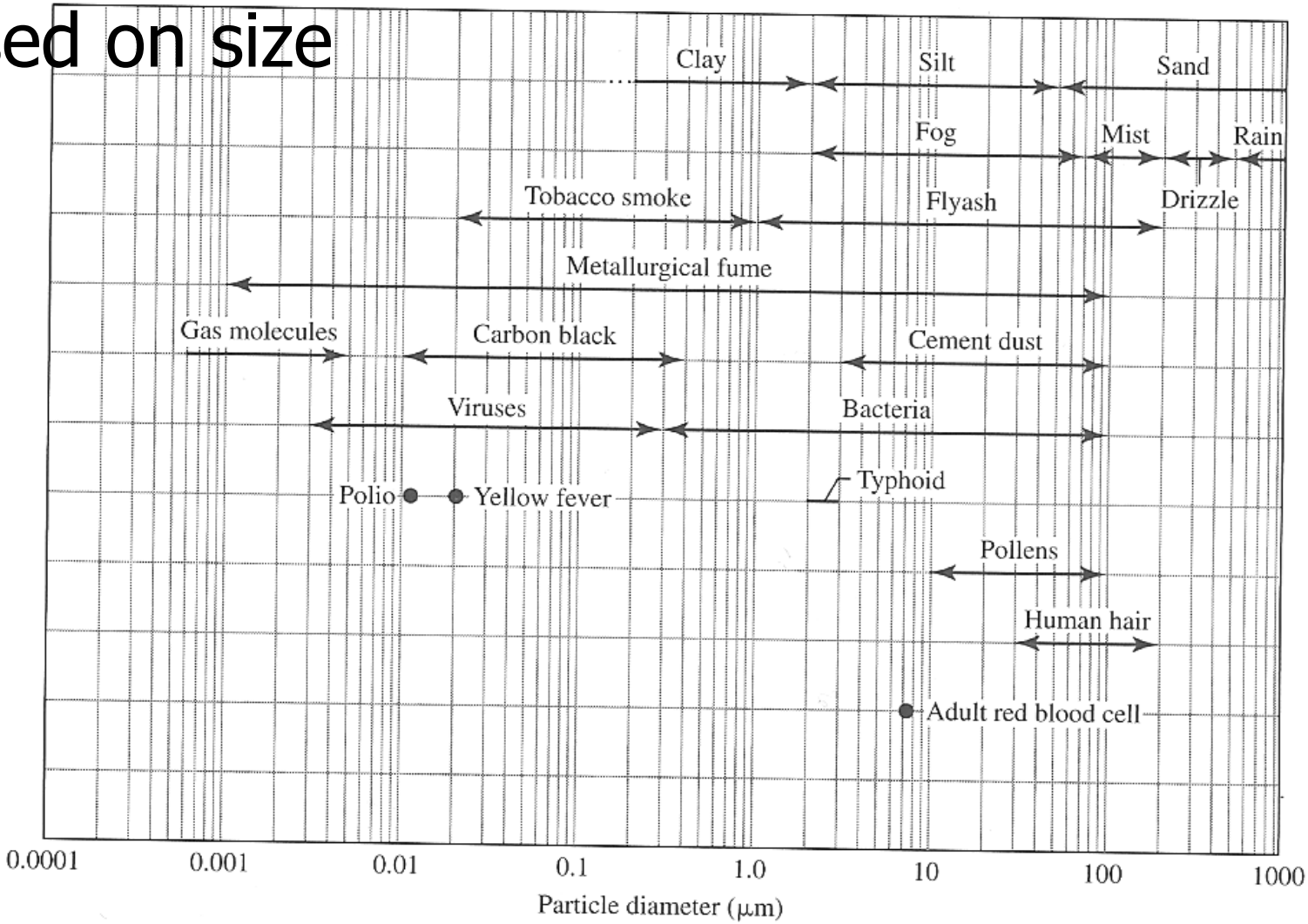
Source: World Health Organization, *Air Pollution,* 1961, p. 180.

Hazardous Air Pollutants

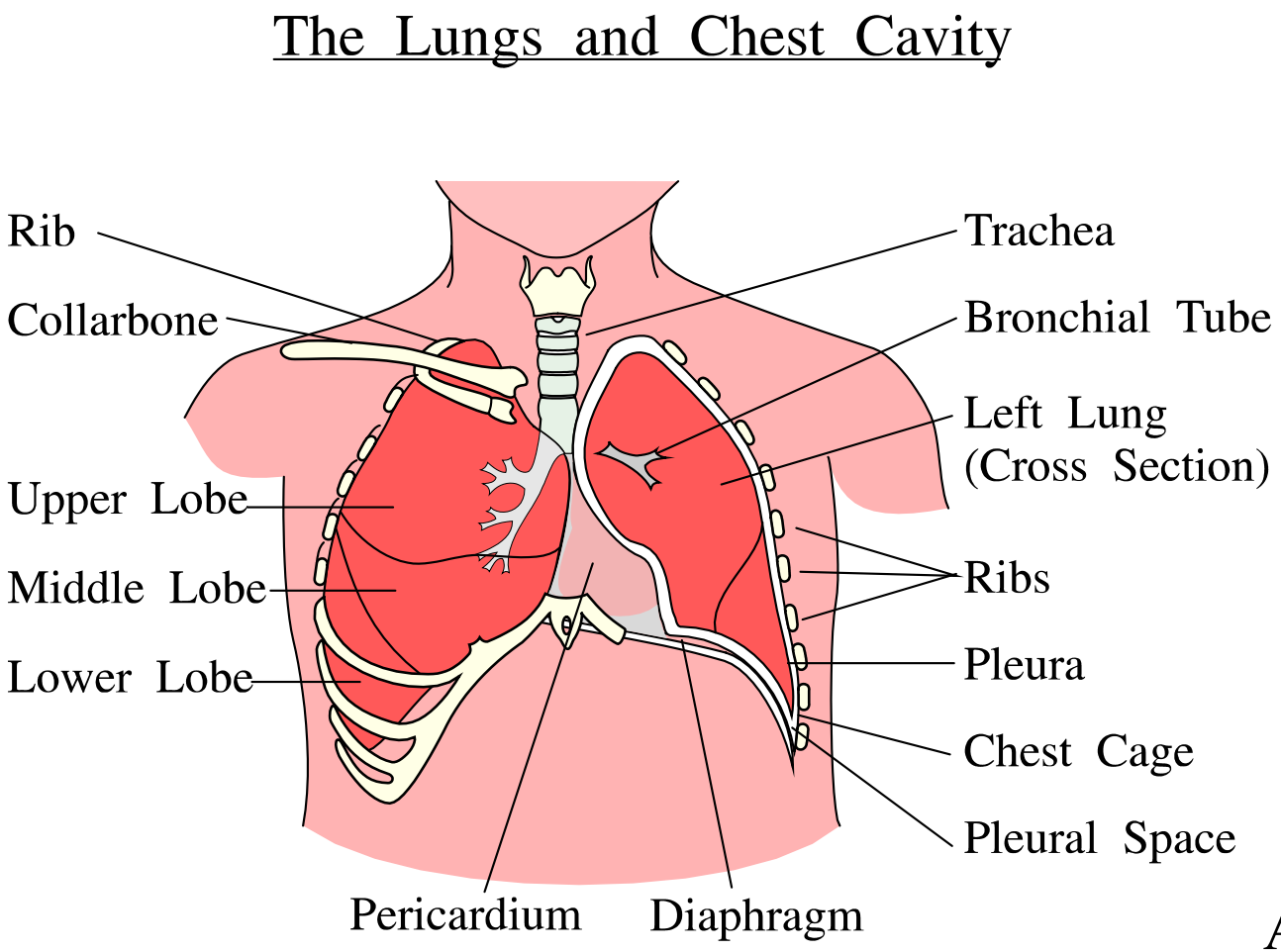
Source	Hazardous Air Pollutants
Dry cleaning	Tetrachloroethylene
Plastics production	Various volatile organics, including methylene chloride, phenol and vinyl chloride
Electric motor manufacture	Organic solvents, organic vapors
Solvent degreasing (cleaning metal parts with organic solvents)	Various volatile organic compounds
Lead smelting	Particulate lead plus particulates from alloying metals such as antimony and arsenic, arsenic vapors
Major appliance manufacturers	Organic solvent vapors, inorganic vapors
Tire manufacturing	Organic vapors, solvent vapors

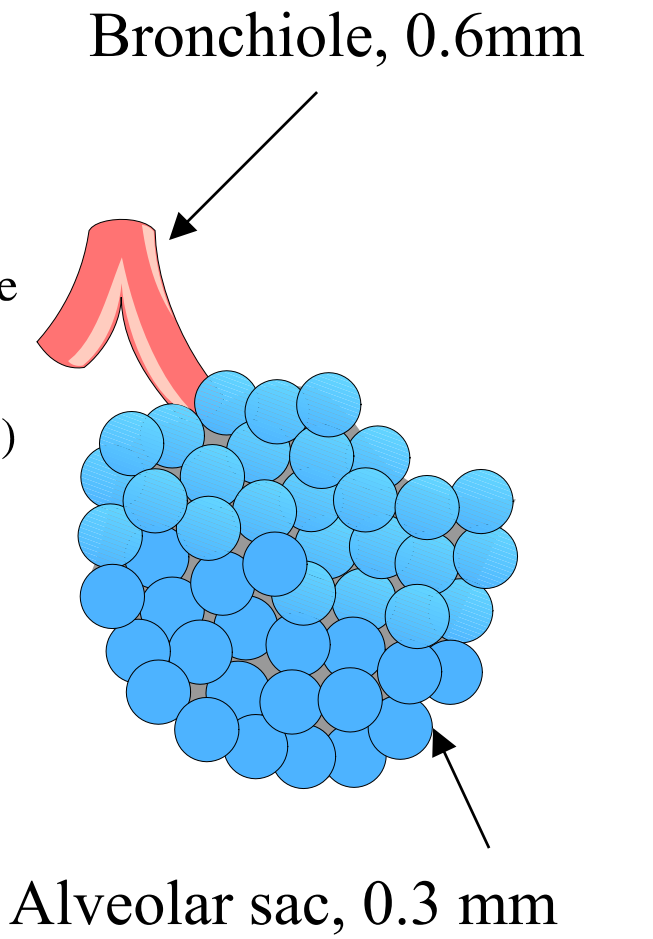
Particulates

- Based on size



Human Respiratory System

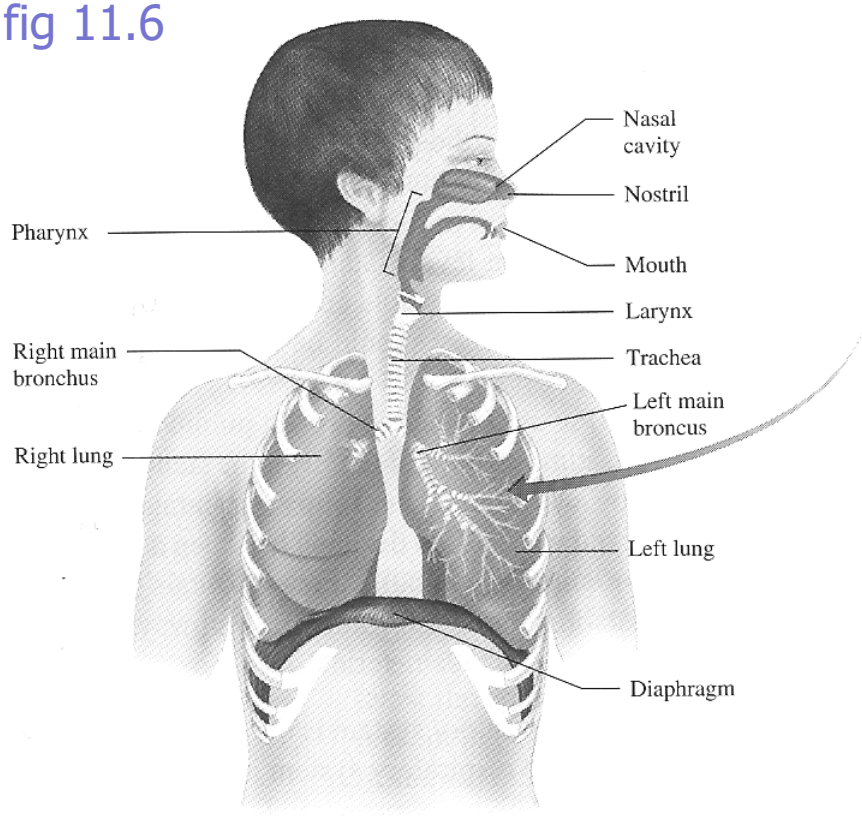


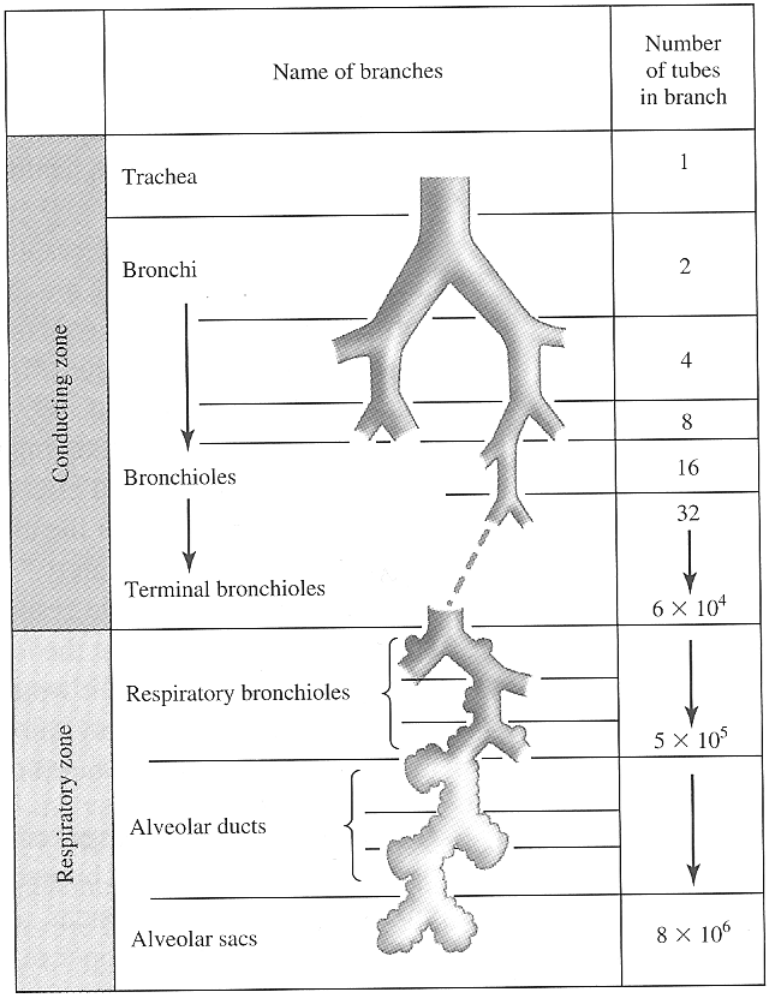


Respiratory system

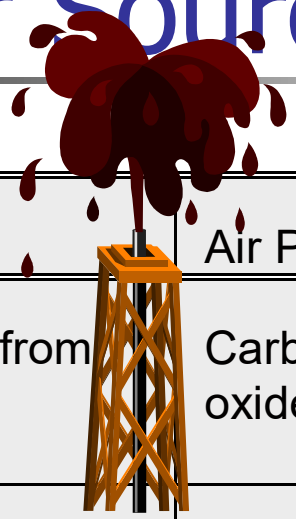
The respiratory system. (*Source:* A. Vander, J. Sherman, D. Luciano, *Human Physiology*, 8th Edition, McGraw-Hill, NY, 2001, Reprinted by permission.)

Similar to fig 11.6

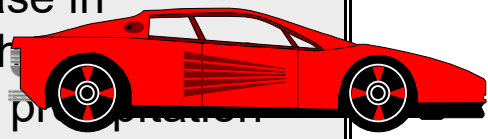




Major Sources of Air Pollution



Activity	Air Pollutants Created	Detrimental Effect
Energy production from fossil fuels	Carbon dioxide, sulfur oxides, particulates	Increase in greenhouse gases, acidic precipitation
Automobiles, other transportation sources	Carbon dioxide, nitrogen and sulfur oxides, products of incomplete combustion	Increase in greenh… acidic pr…itation
Refrigeration devices including home, commercial, and vehicles	Chlorofluorocarbons	Destruction of the stratospheric ozone layer
Industrial manufacturing	Various depending on the industry and process, including toxic materials	Destruction of the stratospheric ozone layer, toxic emissions



Regulations

- 1273: first air pollution regulations passed in England
- US regulations began in LA
- Concern for "states rights" slowed federal action

David Reckhow

Federal Regulations I

Act	Summary
Air Pollution Control Act of 1955, PL 84-159	Established federal funding for air pollution research, federal technical assistance and training.
Air Pollution Control Act Amendments of 1960, PL 87-761	A continuance of the APCA of 1955, and a study of human health effects caused by motor vehicle emissions.
The Clean Air Act of 1963, PL 88-206	Matching grants to state and local government (federal share of 66 to 75 percent), increased research and training, efforts to control air pollution from federal facilities.
Motor Vehicle Air Pollution Control Act of 1965, PL 89-272	Required automobile exhaust emission standards to be met in 1968.
The Air Quality Act of 1967, PL 90-148	Time tables for establishment of air quality criteria for different pollutants, state or federal enforcement of air quality limits. Program was understaffed, under funded and unsuccessful.

Federal Regulations II

Act	Summary
The Clean Air Act Amendments of 1970, PL 91-604	The establishment of national ambient air quality standards for particulates, carbon monoxide, sulfur oxides, hydrocarbons, and others. National emission standards for existing and new facilities, fines and criminal penalties for intentional violation, new stricter automobile emission standards, additional research funding.
The Clean Air Amendments Act of 1977, PL 95-95	Continuance of the 1970 requirements, additional restrictions for "non-attainment areas."
The Clean Air Act of 1990, PL	A complete revamping of the air pollution control regulations, including compliance time tables (3 to 20 years) for major noncompliance areas. Tighter emission standards for vehicles, reformulated gasolines, air toxics requirements, acid rain controls, new permitting program with stiffer civil and criminal penalties.

Key Pollutants I

- Carbon Monoxide (CO)
  - Lethal @ 5000 ppm; some impact @ 20 ppm
  - Reacts with hemoglobin forming carboxyhemoglobin (COHb) which blocks Oxygen
- Hazardous Air Pollutants (HAPs)
  - Includes carcinogens: asbestos, arsenic, benzene, radionuclides
  - Others: beryllium, mercury

PFAS & many others

- Lead (Pb)
  - Cumulative poison with many routes of exposure
  - Anemia to brain damage and paralysis
- Nitrogen Dioxide (NO_2)
  - One of the NO_x gases
  - Causes pulmonary edema

Key Pollutants II

- Photochemical oxidants
  - Ozone and many others
    - Peroxyacetyl nitrate (PAN), acrolein, peroxybenzoyl nitrates (PBzN), aldehydes and NO_x
  - Especially affects those with chronic respiratory disease
- PM_{10} and $PM_{2.5}$
  - Small particles up to 10 μm and 2.5 μm, respectively
    - Penetrate deep into lungs
  - Correlated with pneumonia, asthma, hospital admissions
- Sulfur oxides (SO_x)
  - Includes sulfur dioxide (SO2) and trioxide (SO3)
  - Synergistic effect with high particulat levels
    - Helps to bring SO_x deep into lungs

Standards

TABLE 11–1 National Ambient Air Quality Standards (NAAQS)

Criteria Pollutant	Standard Type	Concentration ($\mu g \cdot m^{-3}$)	Concentration (ppm)	Averaging Period or Method	Allowable Exceedances[a]
CO	Primary	10,000	9	8-hour average	Once per year
	Primary	40,000	35	1-hour average	Once per year
Lead	Primary and secondary	1.5		Maximum arithmetic mean measured over a calendar quarter	
NO_2	Primary and secondary	100	0.053	Annual arithmetic mean	
Ozone	Primary and secondary	235	0.12	Maximum hourly average	Once per year
Ozone[b]	Primary and secondary	157	0.08	8-h average	[c]
Particulate matter (PM_{10})[d]	Primary and secondary	150		24-h average	One day per year
	Primary and secondary	50		Annual arithmetic mean	
($PM_{2.5}$)[b]	Primary and secondary	65		24-h average	One day per year
		15		Annual arithmetic mean	
SO_2	Primary	80	0.03	Annual arithmetic mean	
	Primary	365	0.14	Maximum 24-h concentration	Once per year
SO_2	Secondary	1300	0.5	Maximum 3-h concentration	Once per year

CAA of 1990

- Two regulatory categories
  - Primary ambient air quality standards
    - to protect human health
  - Secondary ambient air quality standards
    - to protect "human welfare" (the environment & infrastructure)
- Major new efforts
  - additional removal of sulfur and nitrogen oxides
  - phaseout of CFCs

Units of Expression

- Typically $\mu g/m^3$ (mass per volume) for gaseous, nongaseous, or particulate matter
- ppm (parts per million) is also used for gases

$$\text{ppm} = \frac{\text{volume of contaminant}}{10^6 \text{ volumes of (air + contaminant)}}$$

And this generally reduces to:

$$\text{ppm} = \frac{\text{volume of contaminant}}{10^6 \text{ volume of air}}$$

Units of Expression (cont.)

Conversion to mass per unit volume requires the ideal gas law (22.3 L / mole).

$$C_{contaminant} = \frac{V_{contaminant}}{10^6\ V_{air}} = \frac{V_{cont} \times \frac{Mole}{22.4\,L} \times \frac{10^3\ L}{m^3} \times \frac{GMW\ g}{Mole} \times \frac{10^6 \mu g}{g}}{10^6\ V_{air}}$$

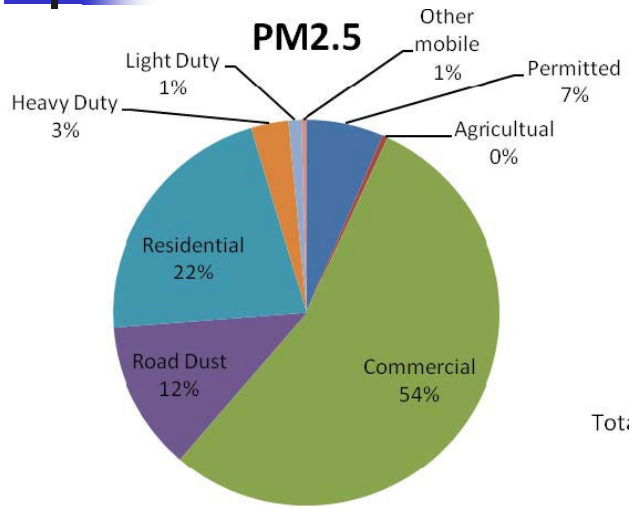
Because $\frac{V_{contaminant}}{10^6\ V_{air}}$ is the ppm of contaminant,

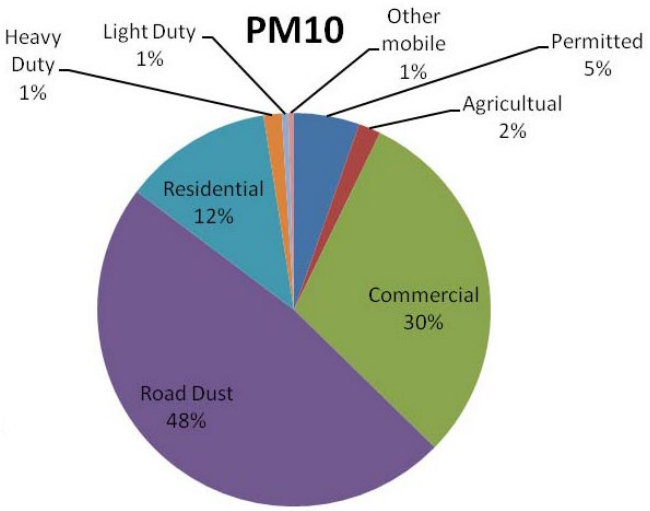
$$C_{contaminant}\left[\frac{\mu g}{m^3}\right] = \frac{ppm \times 10^3\ GMW}{22.4}$$

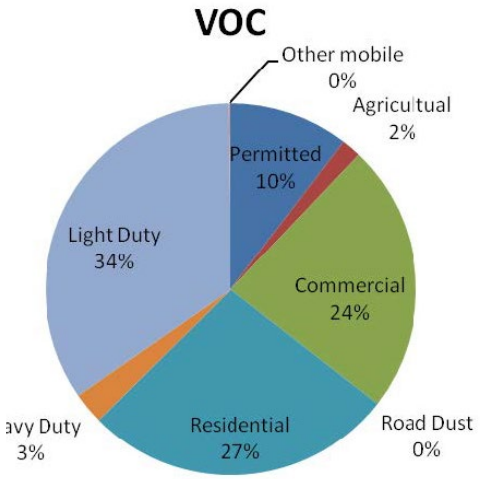
National Ambient Air Quality Standards

Pollutant	Averaging time	Primary Std. ($\mu g/m^3$)
Carbon Monoxide	8 h	10,000 (9ppm)
	1 h	40,000 (35ppm)
Hydrocarbons	3 h	160 (0.24ppm)
Lead	Monthly	1.5
Nitrogen Dioxide	Annual	100 (0.05ppm)
	1 h	500 (0.25ppm)
Photochemical Oxidants	1 h	240 (0.12ppm)
Sulfur dioxide	Annual	80 (0.03ppm)
	24 h	365 (0.14ppm)
Total suspended particulates	Annual	75
	24 h	260

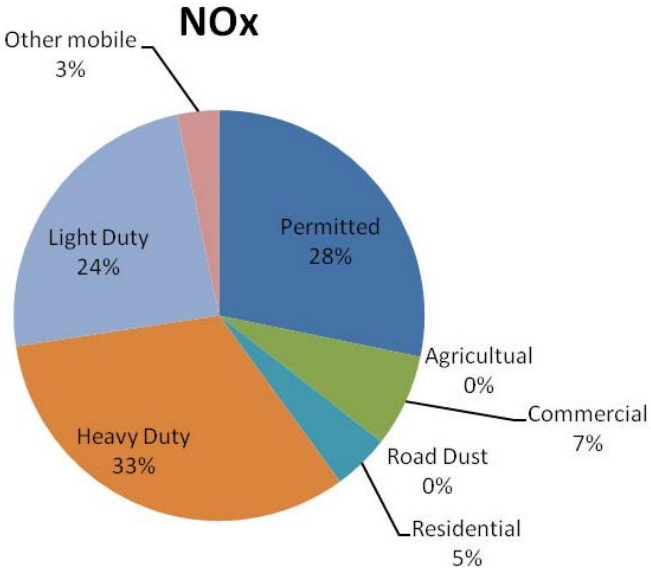
5 major air pollutants

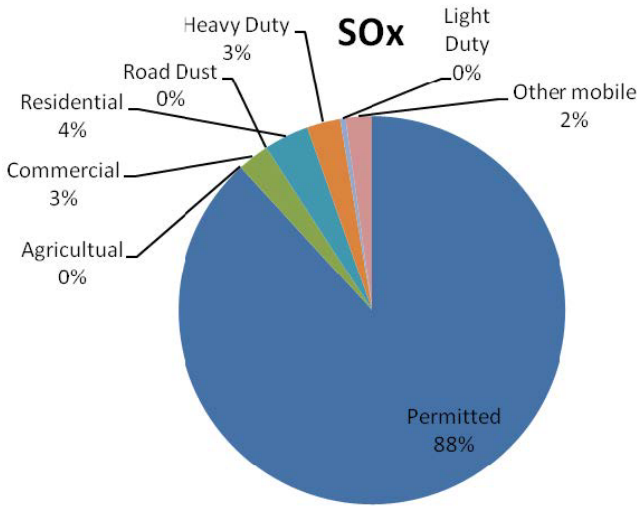






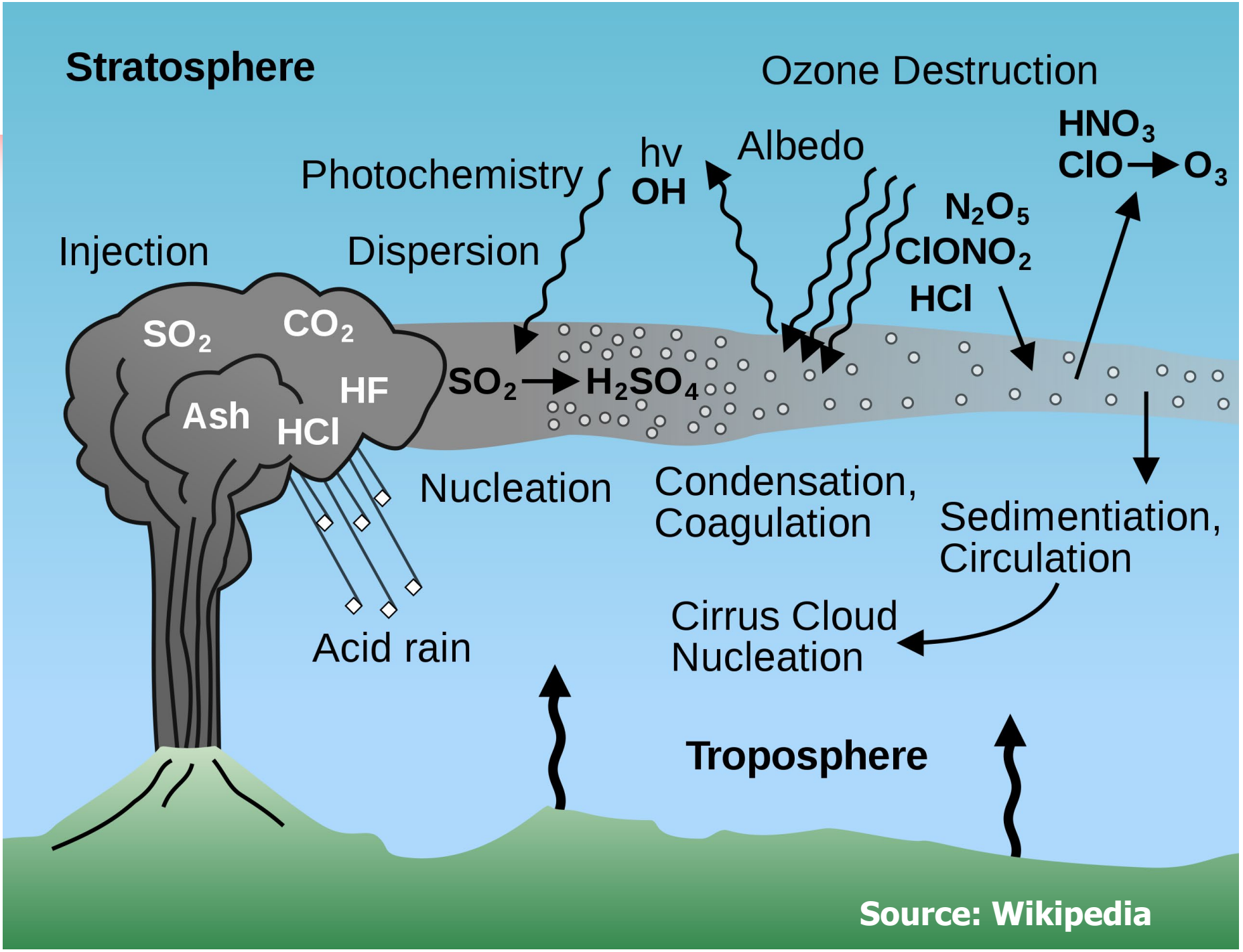
Alberni Valley, Vancouver Island, BC, 2006
https://www.acrd.bc.ca/main-sources-of-air-pollution





Volcanic Sources

- White Island, New Zealand


Stratosphere
Ozone Destruction
HNO_3
ClO → O_3
hv
OH
Albedo
Photochemistry
N_2O_5
$ClONO_2$
HCl
Injection
Dispersion
SO_2
CO_2
HF
Ash
HCl
SO_2 → H_2SO_4
Nucleation
Condensation,
Coagulation
Sedimentiation,
Circulation
Cirrus Cloud
Nucleation
Acid rain
Troposphere
Source: Wikipedia

Carbon Monoxide

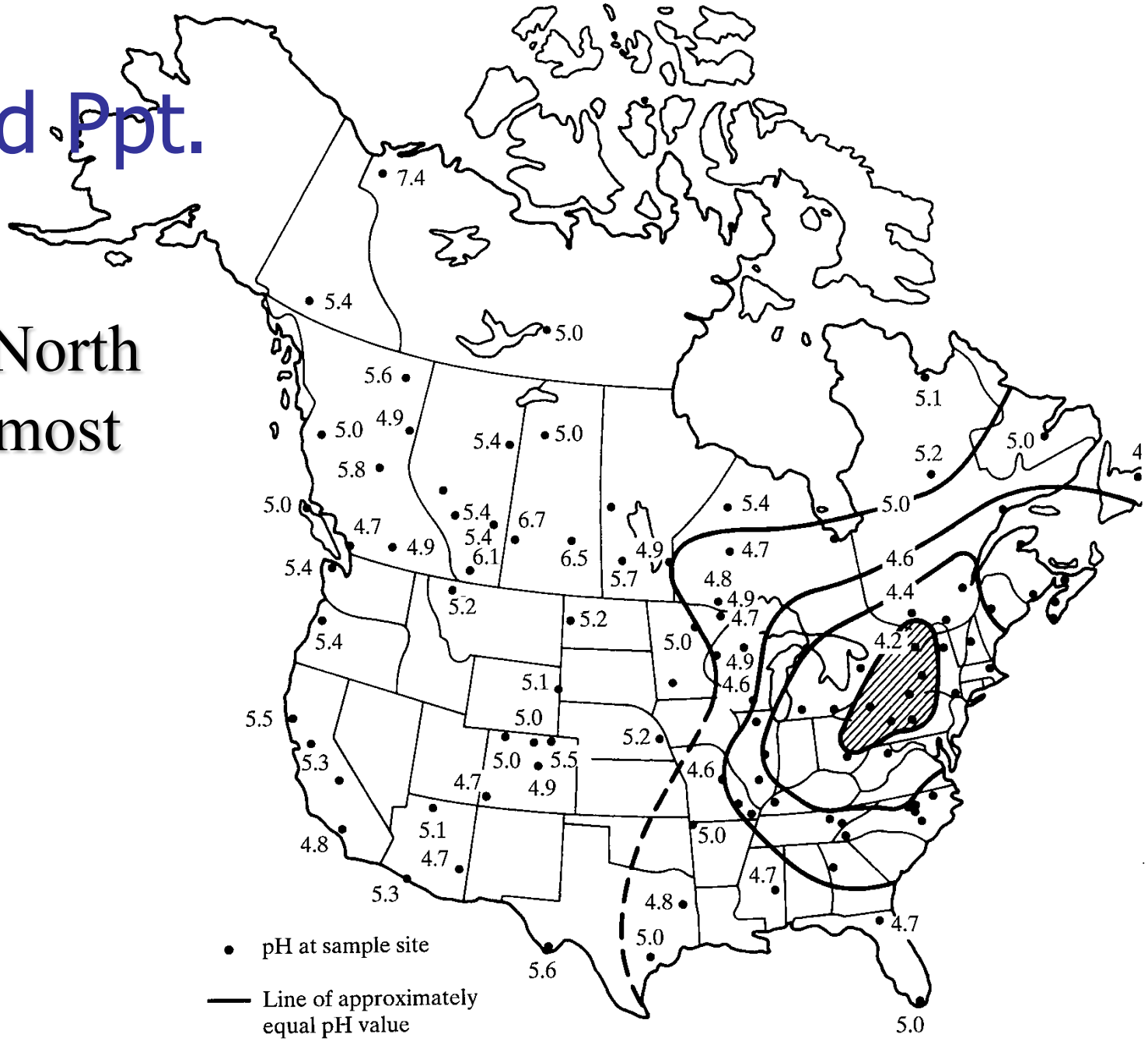
- Product of incomplete oxidation
  - Biological oxidation
    - Formation of methane, resulting in CO
  - Chemical combustion
    - Burning of fossil fuels
  - Anthropogenic sources account for most CO production
    - Discharge to atmosphere has been increasing
    - No change in levels, however
    - loss mechanisms are keeping up
      - Formation of CO2 by reaction with OH radicals
      - Removal by soil microorganisms
      - Loss to stratosphere

Acidic Air Pollutants

- Environmental Impacts
  - consumes alkalinity and lowers pH
  - may cause release of metals in water (Al) which can lead to toxicity
  - large areas of Northeast US are already affected
- Sources
  - Sulfur and nitrogen oxides that combine with water to form acids

Acid Ppt.

Areas in North America most affected



Sulfur Oxides

- Sources
  - Natural: 10 Tg
  - Anthropogenic: 75 Tg
- Processes
  - Hydration
  - Oxidation to SO_4^{-2}
    - Catalytic (with Fe^{+3}, Mn^{+2}, NH_3)
    - Photochemical
- Control

$$S + O_2 \rightarrow SO_2$$

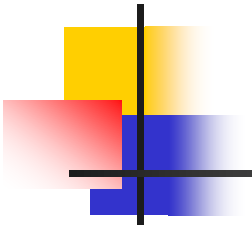
$$SO_2 + \tfrac{1}{2} O_2 \rightarrow SO_3$$

SO_x

$$SO_2 + H_2O \rightarrow H_2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$H_2SO_3 + CaO \rightarrow CaSO_3 + H_2O$$



- To next lecture