Ch. 21 Notes: Atmospheric Pollution

21.1 Notes

I. Air Pollution Essentials

A. Pollutants and Atmospheric Cleansing

1) **gases** in Earth's atmosphere
   a) fixed concentrations: N_2, O_2, *Ar, Ne, He, Kr,* H_2, *Xe*
   b) variable concentrations: H_2O, CO_2, CH_4, N_2O, *CO,* O_3, NH_3, NO_2, SO_2, *NO,* H_2S
2) **air pollutants**—gases, aerosols, and particulates with harmful effects
3) atmospheric cleansing – natural processes
   a) *dispersion / dilution in the atmosphere*
   b) *breakdown of compounds in the soil by microorganisms*
   c) **hydroxyl radical (OH*),** the "detergent of the troposphere"
      - the neutral form of the hydroxide ion (OH^-)
      - *oxidizes many pollutants, often the first step toward removal*
      - primary removal mechanism for CO: $OH^* + CO \rightarrow H^* + CO_2$
      - Volatile Organic Compounds (VOCs) reactions:

$OH^* + RH \rightarrow H_2O + R^*$ (alkyl radical formation) $R^* + O_2 \rightarrow RO_2^*$ (*peroxy radical* formation)

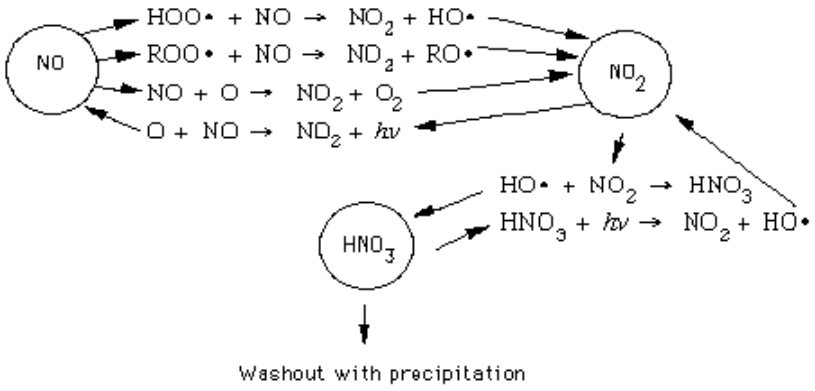
      - NO_x reactions:

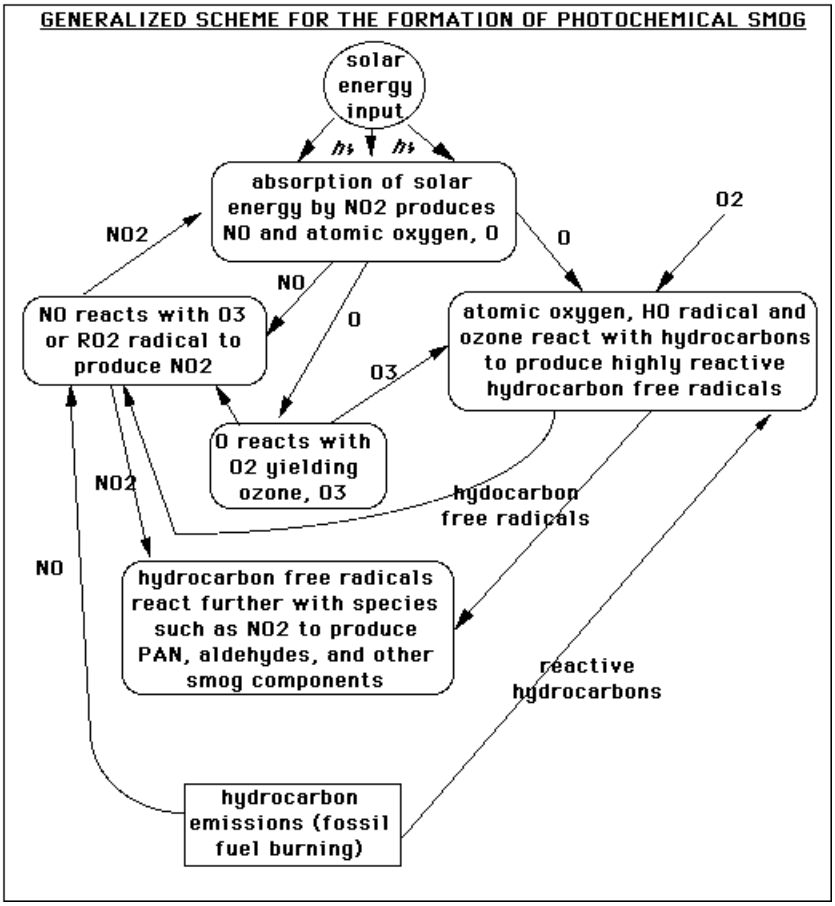
$HO_2^* + NO \rightarrow NO_2 + OH^*$
$OH^* + NO_2 \rightarrow HNO_3$ (*nitric acid* formation)

B. The Appearance of Smog ("smog" = smoke + fog)

1) **industrial smog** ("reducing smog")
   a) London—*coal combustion* causes emission of *particulate matter and water vapor,* SO_x, NO_x
   b) produces eye irritation and poor visibility
2) **photochemical smog** ("oxidizing smog," "urban smog")
   c) *sources for formation*
      - *light energy (uv)*
      - *hydrocarbons/VOCs (from fossil fuel combustion)*
      - NO_x *(from fossil fuel combustion)*
   d) often contains ozone (O_3)
   e) large reduction in visibility
   f) NO_2 makes smog a brown color
   g) Los Angeles basin—photochemical smog

Two diagrams from http://www.shodor.org/master/environmental/air/photochem/smogapplication.html





3) **temperature inversions**—*cooler air layered below warmer air*
   a) traps smog close to the ground
   b) relatively short-lived (morning sun dissipates it)
4) impact of smog
   a) aggravates asthma, emphysema, and other respiratory issues
   b) air-pollution disaster = when lethal effects are observed

Air quality by state: http://www.stateoftheair.org/

The most polluted U.S. cities, 2008

Rank	Short-term Particulates	Year-round Particulates	Ozone
1	Pittsburgh (PA)	Bakersfield (CA)	Los Angeles (CA)
2	Fresno (CA)	Pittsburgh (PA)	Bakersfield (CA)
3	Bakersfield (CA)	Los Angeles (CA)	Visalia (CA)
4	Los Angeles (CA)	Visalia (CA)	Fresno (CA)
5	Birmingham (AL)	Birmingham (AL)	Houston (TX)
6	Salt Lake City (UT)	Hanford (CA)	Sacramento (CA)
7	Sacramento (CA)	Fresno (CA)	Dallas-Forth Worth (TX)
8	Logan	Cincinnati (OH)	Charlotte (NC)
9	Detroit (MI) – tie for #9	Detroit (MI)	Phoenix (AZ)
10	Chirago (IL) – tie for #9	Birmingham (AL)	El Centro (CA)

Source: The American Lung Association

II. Air Pollutants – General Overview

From weather.com:

"*The average adult breathes over 3,000 gallons of air every day*. Children breathe even more air per pound of body weight and are more susceptible to air pollution. The elderly are also more sensitive to air pollution because they often have heart or lung disease…

The AQI (Air Quality Index) is an index for forecasting daily air quality. It tells you how clean or polluted your air is, and what associated health concerns you should be aware of. The AQI focuses on health effects that can happen within a few hours or days after breathing polluted air.

The EPA uses the AQI for five major air pollutants regulated by the Clean Air Act: ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide and nitrogen dioxide. For each of these pollutants, EPA has established national air quality standards to protect against harmful health effects."

A. *Natural Air Pollution*

1) *types*

volcanic eruptions
forest fires
decomposition of plants and animals
soil erosion
pollen and mold spores
ocean spray

VOC: volatile organic compounds from vegetation (such as isoprene)
ozone from electrical storms
stratospheric intrusion
photochemical reactions

2) Why are these not a threat?
   a) levels of contaminants are usually very low
   b) usually long distance between the source and dense human populations
   c) episodic and short-lived

B. *Human-made pollution = anthropogenic*

1) *smog*—severe ambient pollution conditions
2) *haze*
   a) moderate reduction in visibility
   b) summertime conditions in Midwest, NE and SE U.S.
   c) mainly caused by particulate matter (PM) / sulfates
3) *nontraditional air pollutants*
   a) *noise*
   b) *heat*
   c) *ionizing radiation*
   d) *em (electromagnetic) fields*
4) *traditional air pollutants: gases, aerosols, and particulate matter*
   a) **suspended particulate matter (PM)**
   b) **VOCs – volatile organic compounds**
   c) **CO – carbon monoxide**
   d) **NO_x – nitrogen oxides**
   e) **SO_x – sulfur oxides**
   f) **Pb and other heavy metals**
   g) **O_3 and other photochemical oxidants *(secondary)***
   h) **air toxics / Rn (radon)**
   i) **PAN – peroxyacteyl nitrates *(secondary)***

21.2 Notes

III. Major Air Pollutants and Their Sources (from weather.com and the EPA)

A. **primary pollutants**

1) **particulate matter (PM), VOCs, CO, NO_x, SO_x, Pb**

2) *they are direct products from combustion or other actions*

B. **secondary pollutants**—*formed from reaction of primary pollutants*
ozone O_3, PANs, sulfuric acid H_2SO_4, nitric acid HNO_3

C. **emissions**—*amounts of a substance given off*

IV. More on Sources of Pollutants

A. **Suspended Particulate Matter (PM)**

1) general info.

a) *particles found in air: dust, dirt, soot, smoke, and liquid droplets*

b) **$PM_{2.5}$** *(less than 2.5 μm in diameter): fine particles*

c) **PM_{10}** *(between 2.5 and 10 μm in diameter): coarse dust*

d) carried over long distances by wind; settle on ground or water

e) solid and *liquid* suspension in air = *aerosol*

- types: fume aerosols, duct aerosols, mists, smoke

2) sources of fine particles

a) all types of *combustion* (motor vehicles, power plants, wood, etc.)

b) some industrial processes

3) sources of coarse particles

a) *crushing or grinding* operations

b) dust from paved or unpaved roads

4) *health effects*

a) *can be inhaled into, and accumulate in, the respiratory system*

b) *coughing and painful breathing; shortness of breath*

c) can aggravate asthma and chronic bronchitis

d) adverse health effects from chronic, intermediate, or acute exposure

e) *premature death or hospital admissions*: very young, elderly, people with chronic obstructive pulmonary disease/congestive heart disease

5) *environmental effects*

a) *acidifying streams and lakes*

b) *changing nutrient balance in coastal waters and large river basins*

c) *depleting soil nutrients*

d) *damaging sensitive forests and farm crops*

e) *affecting the diversity of ecosystems*

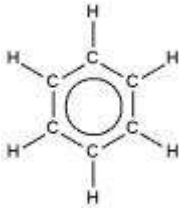
f) soot stains and damages stone and other materials, including culturally important objects such as monuments and statues

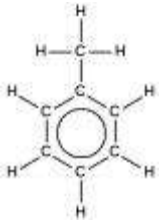
B. **VOCs – volatile organic compounds**

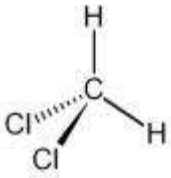
1) general info.

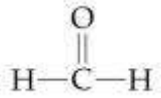
a) *volatile*—easily escaping into the air

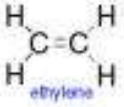
b) chemicals such as benzene, toluene, methylene chloride, formaldehyde, ethylene


benzene


toluene


methylene chloride


formaldehyde


ethylene

2) sources
   a) *combustion of fuel* (gasoline, oil, wood coal, natural gas, etc.); cars…
   b) *solvents, paints, glues*, etc.

3) health effects
   a) *many are classified as hazardous air pollutants (HAZMATs)*
   b) *many are carcinogenic*
4) environmental effects
   a) contribute to *ozone formation*: **VOC + NO_x + Sunlight = O_3**
   b) cause damage to plants

C. **CO – carbon monoxide**

1) general info.: colorless, odorless gas 

(One coordinate bond and two normal covalent bonds between C and O. C is the electron acceptor and oxygen is the electron donor.)

2) outdoor sources
   a) *incomplete combustion of fuel*: $C_xH_y + O_2 \rightarrow CO + H_2O$
   b) *motor vehicle exhaust*: ~56% of U.S. CO emissions
   c) *non-road vehicles and boats*: ~22%
   d) *industrial*: metal processing, chemical manufacturing
   e) residential *wood burning*
   f) forest fires
   g) seen in colder months' temperature inversions
3) *indoor sources*
   a) *woodstoves, gas stoves*
   b) *cigarette smoke*
   c) *unvented gas / kerosene space heaters*
4) *health effects*
   a) *at high levels, it is poisonous*
   b) *at very high levels, it is lethal*
   c) *reduces oxygen delivery to the body's organs*
   d) affects people with heart disease
   e) vision problems, reduced ability to work or learn, reduced manual dexterity
5) environmental effects: contributes to the formation of ground-level ozone

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D. **NO_x – nitrogen oxides**

1) general info.
   a) *NO_x family— highly reactive gases*
   b) *nitrogen dioxide (NO_2)—brown gas with a stinging odor*
2) sources
   a) *combustion of fuel at high temperatures*

b) *motor vehicle exhaust*
c) stationary sources: *electric utilities*, industrial boilers

3) *health effects*
a) *coughing, wheezing, and shortness of breath*
b) *aggravates asthma and existing respiratory problems*
c) long-term exposure:
- may increase susceptibility to respiratory infection
- may cause permanent structural changes in the lungs

4) *environmental effects*
a) *major role in the reactions forming ground-level ozone*
VOC + NO_x + Sunlight = O_3
b) *component of smog*
c) *strong oxidizing agent; reacts to form nitric acid (HNO_3)* and toxic organic nitrates
d) *eutrophication of bodies of water*

E. **SO_x – sulfur oxides**
1) general info
a) *SO_2 sulfur dioxide*
b) *$(SO_4)^{2-}$ sulfate ion*
2) sources
a) *combustion of sulfur-containing fuel* (coal, oil)
- over 65% from coal-burning power plants

b) *gasoline extraction from oil*
c) *metal extraction from ore*
d) petroleum refineries, cement manufacturing, and metal processing facilities, locomotives, large ships, some diesel equipment

3) health effects
a) contributes to *respiratory illness*, particularly in children and the elderly
b) aggravates asthma
c) bronchoconstriction: wheezing, chest tightness, shortness of breath
d) *aggravates existing heart and lung diseases*
e) chronic exposure: can cause respiratory illness, alter the lung's defense mechanisms, and aggravate existing cardiovascular disease

4) environmental effects
a) *dissolves easily in water: SO_2 contributes to the formation of acid precipitation (important!)*
b) *visibility impairment (haze) by sulfate particles*
c) *plant and water damage by acid rain*
- acid rain damages forests and crops
- changes the makeup of soil
- makes bodies of water acidic and unsuitable for fish
- continued exposure changes ecosystem balance

d) aesthetic damage: accelerates decay of building materials and paints

F. **Pb and other heavy metals**
1) general info.:

Aluminum, Al	Antimony, Sb	*Arsenic, As*	Beryllium, Be

Cadmium, Cd	*Chromium, Cr*	Cobalt, Co	*Copper, Cu*
Iron, Fe	*Lead, Pb*	Manganese, Mn	*Mercury, Hg*
Molybdenum, Mo	Nickel, Ni	Selenium, Se	Silver, Ag
Tin, Sn	Vanadium, V	*Zinc, Zn*	

2) sources
   a) leaded gasoline (being phased out)
   b) *paint, inks, dyes*
   c) smelters (metal refineries)
   d) manufacture of *lead storage batteries*
   e) *pesticides*
   f) *industrial use*
3) health effects (lead)
   a) *brain and other nervous system damage*
   b) may cause birth defects
   c) may cause cancer
   d) digestive problems
4) environmental effects: *harm wildlife*

G. **O_3** and other **photochemical oxidants**
1) general info
   a) *"good ozone" = stratospheric ozone*
   b) *"bad ozone" = tropospheric (ground-level) ozone*
2) sources
   a) *chemicals* from cars, power plants, industrial boilers, refineries, chemical plants, etc. *…reacting with sunlight*
   b) O_3 pollution is *a concern during the summer months* with optimal conditions to form ground-level O_3(abundant sunlight, hot temperatures)
   c) the length of the *ozone season* varies from one area of the U.S. to another; states in the S-SW U.S. may have an ozone season lasting the entire year
3) *health effects*
   a) *irritation and inflammation of lung airways*
   b) *wheezing, coughing*
   c) *painful deep breathing, breathing difficulties during exercise or outdoor activities*
   d) *aggravated asthma, reduced lung capacity*
   e) *increased susceptibility to respiratory illnesses*

- Repeated exposure to ozone pollution for several months may cause permanent lung damage.
- Anyone who spends time outdoors, especially in the summer, is at risk.
- Ozone damage can occur without any noticeable signs.
- Ozone continues to cause lung damage even when the symptoms have disappeared.

4) environmental effects
   a) damages crops and other vegetation
   b) major component of photochemical smog

- interferes with the ability of plants to produce and store food, making them more susceptible to disease, insects, other pollutants, and harsh weather
- damages plant leaves
- reduces crop and forest yields
- increases plant vulnerability to disease, pests, and harsh weather

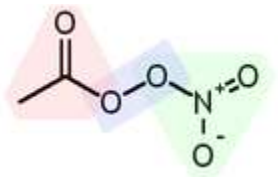
H. **Hazardous air pollutants (HAPs)** or **air toxics**

1) general info. from www.epa.gov
   a) *EPA lists 187current toxic air pollutants* www.epa.gov/ttn/atw/188polls.html
   b) "Sources are to use **Maximum Available Control Technology (MACT)** to reduce pollutant releases; this is a very high level of pollution control."
2) sources
   a) *breathing contaminated air*
   b) *eating contaminated food products*
   c) *drinking water contaminated by toxic air pollutants*
   d) *ingesting contaminated soil (especially with children)*
   e) *skin contact with contaminated soil, dust, or water*
3) health effects
   a) *increased risk of cancer*
   b) *damage to the immune system*
   c) *neurological, reproductive (e.g., reduced fertility), developmental, respiratory problems*
4) environmental effects: *biomagnification*

I. **PAN – peroxyacteyl nitrates**

1) general info
2) sources: photochemical reactions (VOC + NO_x)
3) health effects
   a) *low concentrations: eye/lung irritation*
   b) *increased risk of skin cancer*
4) environmental effects: *vegetation damage*

the most common PAN



FYI: Humidity as a contributor to air quality

Possible Effects of Indoor Humidity

TOO DRY (< 30%)

- Damage to wood floors, furniture, musical instruments
- Static electricity; electronic equipment damage
- Respiratory, throat, and skin irritations
- Increased dust

TOO WET (> 50%)

- Termites, cockroaches, and other insects
- Condensation and stains on walls, ceilings, windows
- Flaking paint and peeling wallpaper
- Mold, mildew, dust mite growth; allergic reactions

V. Acid Deposition

A. Acid – base characteristics

1) **acids**

a) *compounds producing hydrogen ions (H^+) when dissolved in water*

b) acidic solutions: $[H^+] > [OH^-]$

c) acid formulas usually begin with H (or end with COOH)

d) examples

hydrochloric – HCl	*sulfuric – H_2SO_4*
nitric – HNO_3	*acetic – CH_3COOH or $HC_2H_3O_2$*
phosphoric – H_3PO_4	*carbonic – H_2CO_3*

2) **bases**

a) *produce hydroxide ions (OH^-) when dissolved in water*

b) basic (alkaline) solutions: $[OH^-] > [H^+]$

c) base formulas typically end in OH

d) examples

sodium hydroxide – NaOH	*calcium hydroxide – $Ca(OH)_2$*
potassium hydroxide – KOH	*ammonium hydroxide – NH_4OH*

B. Water

1) ion product constant for water = K_w

$K_w = [H^+]\,[OH^-] = 10^{-14}$ M

2) self-ionization of water

$H_2O \rightarrow H^+ + OH^-$

water → hydrogen ion + hydroxide ion

$\underline{2}\ H_2O \rightarrow H_3O^+ + OH^-$

water → hydronium ion + hydroxide ion

3) *pure water is neutral: $[H^+] = [OH^-]$*

$[H^+] = 10^{-7}$ M and $[OH^-] = 10^{-7}$ M

C. What is acid deposition?

1) *acid rain*— acids falling out of the atmosphere

2) **acid precipitation**—precipitation with a pH of 5.5 or less

3) **acid deposition**

a) *wet deposition*: acidic rain, fog, and snow

b) *dry deposition*: acidic gases and particles

4) Normal rain is slightly acidic because CO_2 dissolves into it, so it has a pH of about 5.5.

5) The most acidic rain falling in the U.S. has a pH of about 4.3. (http://www.epa.gov/acidrain/measure/index.html)

D. How is it spread?

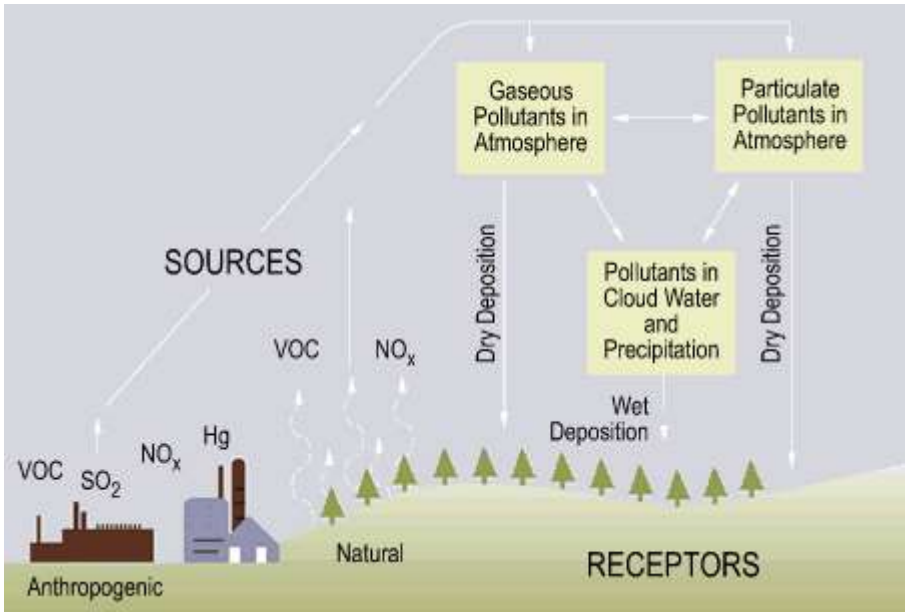
- prevailing winds can blow acidic compounds over hundreds of miles

E. Causes

1) *sulfur dioxide (SO_2)* → *forms* **H_2SO_4 (sulfuric acid)**

2) *nitrogen oxides (NO_x)* → *forms* **HNO_3 (nitric acid)**

- In the U.S., ~ 2/3 of all SO_2 and ~ 1/4 of all NO_x comes from electric power generation that relies on burning fossil fuel



F. How it is measured

1) **pH** = *the negative logarithm of the hydrogen ion concentration*

pH = -log [H^+]

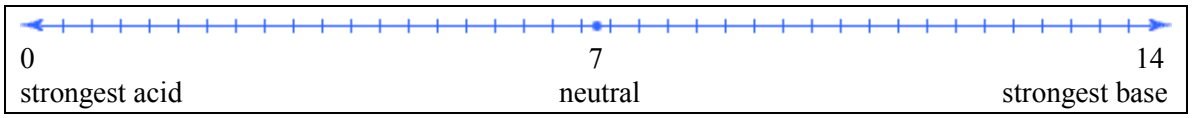
2) *pH is a measure of the acidity or basic quality (alkalinity) of a substance*

3) pH values

a) *acid pH < 7*

b) *base pH > 7*

c) *neutral pH = 7*



4) **pOH** = *the negative logarithm of the hydroxide ion concentration*

pOH = -log [OH^-]	**pH + pOH = 14**

E1) If [H+] of a solution = 1.0×10^{-11} M…

a) Find pH. b) Find pOH. c) Find [OH^-]. d) Acid, base, or neutral?

a) [H^+] = 1.0×10^{-11} M so $\boxed{\text{pH} = 11}$

b) pH + pOH = 14 11 + pOH = 14 $\boxed{\text{pOH} = 3}$

c) [H^+] [OH^-] = 10^{-14} M [10^{-11}] [OH^-] = 10^{-14} M $\boxed{[OH^-] = 10^{-3}\text{ M}}$

d) base (pH = 11)

E2) If [OH^-] of a solution = 1.0×10^{-9} M…

a) Find pOH. b) Find pH. c) Find [H^+]. d) Acid, base, or neutral?

a) [OH^-] = 1.0×10^{-9} M so $\boxed{\text{pOH} = 9}$

b) pH + pOH = 14 pH + 9 = 14 $\boxed{\text{pH} = 5}$

c) [H^+] [OH^-] = 10^{-14} M [H^+] [10^{-9}] = 10^{-14} M $\boxed{[H^+] = 10^{-5}\text{ M}}$

d) acid (pH = 5)

G. Monitoring through EPA-sponsored networks
   1) The *National Atmospheric Deposition Program* measures wet deposition.
   2) The *Clean Air Status and Trends Network* (CASTNET) measures dry deposition.
   3) they check acid rain's pH and the chemicals that cause acid rain

21.3 Notes

VI. Impacts of Air Pollutants

A. Over the last decade (from the EPA)
   1) ambient SO_2 and sulfate levels are down in the eastern U.S.
   2) wet sulfate deposition has decreased in the NE and SE U.S.
   3) signs of recovery in acidified lakes and streams are evident in the Adirondacks, the northern Appalachian Plateau, and the upper Midwest. These signs include lower concentrations of sulfates, nitrates, and improvements in acid neutralizing capacity.

B. effects (see previous sections)
   1) *chronic effects* (gradual deterioration)
   2) *acute effects* (severe and sudden)
   3) *carcinogenic effects* (cancer-causing)
   4) *environmental effects on biotic factors*
      a) effects on *surface waters*

http://www.epa.gov/acidrain/effects/surface_water.html

- most lakes and streams: pH 6-8
- *affects sensitive bodies of water which are located in watersheds whose soils have a limited ability to neutralize acidic compounds (called* **buffering capacity***)*
- water itself and its surrounding soil cannot buffer the acid rain enough to neutralize it
- acid rain also releases Al^{3+} from soils into lakes and streams, which is highly toxic to many species of aquatic organisms

      c) effects on *forests*

http://www.epa.gov/acidrain/effects/forests.html

- trees do not grow as quickly at a healthy pace
- leaves and needles turn brown and fall off
- individual trees or entire areas of the forest may die off
- soil degradation
- combined effects with pollution, insects, disease, drought, or very cold weather

   5) *environmental effects on abiotic factors*
      a) effects on *visibility reduction from SO_2 and NO_x*
      from http://www.epa.gov/acidrain/effects/visibility.html
      - sulfate $(SO_4)^{2-}$ particles account for 50 to 70 % of the visibility reduction in the eastern part of the U.S.
      - in the western U.S., nitrates $(NO_3)^-$ and carbon also play a role

      b) effects on *materials*
      from http://www.epa.gov/acidrain/effects/materials.html
      - corrosion of metals such as bronze
      - deterioration of paint and stone (such as marble and limestone)

- reduce value to society of buildings, bridges, cultural objects
- dry deposition can dirty buildings and other structures, leading to increased maintenance costs

21.4 Notes

VII. Bringing Air Pollution under Control

A. **Clean Air Act (CAA) of 1970** (amended1977 and 1990, minor revisions later)
http://www.epa.gov/air/caa/peg/

1) *1990 Clean Air Act amendments (CAAA)*

Title I – Air Pollution, Prevention and Control
Title II – Emission Standards for Moving Sources
Title III – General
Title IV – Acid Deposition Control
Title V – Permits
Title VI – Stratospheric Ozone Protection

2) **command and control** approach—industry is commanded by law to achieve reduced levels of specific pollutants, using control equipment
3) goals
   a) *set* **ambient standards—***levels which will protect human and environmental health*
      - *primary pollutants: particulates, SO_2, CO, NO_x*
      - *secondary pollutant: O_3*
   b) *set control methods and time tables*
      - lowering the electric power industry's annual emissions of sulfur dioxide (SO_2)
      - lowering the electric power industry's annual emissions of nitrogen oxides (NO_X)
4) CAA established *two types of national air quality standards* from http://www.epa.gov/air/criteria.html
   a) **primary standards**
      - based on the *highest tolerable level* (+/- a safety margin)
      - set limits to protect public health, including the health of sensitive populations such as asthmatics, children, the elderly
   b) **secondary standards**
      - set limits to protect public welfare, including protection against decreased visibility, damage to animals, vegetation, buildings

B. **National Ambient Air Quality Standards (NAAQS)**

a. The EPA has set NAAQS for six principal pollutants, which are called **criteria pollutants**:

particulate matter (PM_{10} and $PM_{2.5}$)	**SO_2**	**CO**	**NO_x**	**O_3**	**Pb**

NAAQS from the EPA

Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air (mg/m^3), and micrograms per cubic meter of air ($\mu g/m^3$).

Pollutant	Primary Standards	Averaging Times	Secondary Standards
Particulate Matter (PM_{10})	50 µg/m^3	Annual (Arith. Mean)	Same as Primary
	150 ug/m^3	24-hour	
Particulate Matter ($PM_{2.5}$)	15.0 µg/m^3	Annual (Arith. Mean)	Same as Primary
	65 ug/m^3	24-hour	
Sulfur Oxides	0.03 ppm	Annual (Arith. Mean)	-------
	0.14 ppm	24-hour	-------
	-------	3-hour	0.5 ppm (1300 ug/m^3)
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour	None
	35 ppm (40 mg/m^3)	1-hour	None
Nitrogen Dioxide	0.053 ppm (100 µg/m^3)	Annual (Arithmetic Mean)	Same as Primary
Ozone	0.08 ppm	8-hour	Same as Primary
Lead	1.5 µg/m^3	Quarterly Average	Same as Primary

C. **National Emission Standards for Hazardous Air Pollutants (NESHAPs)**
general info. from www.epa.gov/oar/oaqps/peg_caa/pegcaa03.html#topic3f

1) *EPA lists 187 current toxic air pollutants*
2) "Sources are to use **Maximum Available Control Technology (MACT)** to reduce pollutant releases; this is a very high level of pollution control."
3) Common Hazardous Air Pollutants (priority HAPs underlined)……..

acrolein	**C_3H_4O**	**formaldehyde**	**H_2CO**
arsenic	**As**	**hydrogen chloride**	**HCl (g)**
asbestos	(mineral fibers: amphiboles, serpentines)	**hydrogen fluoride**	**HF (g)**
benzene	**C_6H_6**	**lead**	**Pb**
beryllium	**Be**	**manganese**	**Mn**
cadmium	**Cd**	**mercury**	**Hg**
chromium	**Cr**	**nickel**	**Ni**
coke oven emissions	(coal; **C**)	**radionuclides**	
dioxins	*(chlorinated dibenzo-p-dioxins **(CDDs)**, chlorinated dibenzofurans **(CDFs)**, certain polychlorinated biphenyls **(PCBs)***	**vinyl chloride**	**CH_2=CHCl**

IX. Control Strategies

A. **command and control**

1) **point sources**—*specific large industrial sites*
2) **area sources**—*local small contributing site, such as a dry cleaner*

B. *reducing particulates (PM)*

1) CAA 1970 banned open burning of refuse
2) CAA 1970 mandated industrial stack emissions reduced to almost zero
3) *attainment plans*
   a) report submitted to the EPA outlining when and how the PM emissions will be reduced
   b) based on **RACT – reasonably available control technology**
4) added PM 2.5 as a new category

C. *limiting pollutants from motor vehicles* = **catalytic converter**

1) *uses a Pt (platinum) catalyst*
2) *VOCs are oxidized into CO_2 and H_2O*
3) *CO changed into CO_2*

D. **CAFE** (corporate average fuel economy) **standards** set by Dept. of Transportation
from http://www.nhtsa.dot.gov/cars/rules/CAFE/overview.htm

Corporate Average Fuel Economy (CAFE) is the sales weighted average fuel economy, expressed in miles per gallon (mpg), of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8,500 lbs. or less, manufactured for sale in the United States, for any given model year. Fuel economy is defined as the average mileage traveled by an automobile per gallon of gasoline (or equivalent amount of other fuel) consumed as measured in accordance with the testing and evaluation protocol set forth by the Environmental Protection Agency (EPA).

What is the origin of CAFE?

The "Energy Policy Conservation Act," enacted into law by Congress in 1975, added Title V, "Improving Automotive Efficiency," to the Motor Vehicle Information and Cost Savings Act and established CAFE standards for passenger cars and light trucks. The Act was passed in response to the 1973-74 Arab oil embargo…"

Congress specified that CAFE standards must be set at the "maximum feasible level." Congress provided that the Department's determinations of maximum feasible level be made in consideration of four factors:

(1) Technological feasibility;
(2) Economic practicability;
(3) Effect of other standards on fuel economy; and
(4) Need of the nation to conserve energy

The penalty for failing to meet CAFE standards recently increased from $5.00 to $5.50 per tenth of a mile per gallon for each tenth under the target value times the total volume of those vehicles manufactured for a given model year.

E. Managing ozone

Go to http://www.epa.gov/airtrends/2005/ozonenbp/summaryregions.pdf

1) old mindset: reduce VOCs to reduce tropospheric O_3 produced
2) new mindset: interactions between VOCs, NO_x, and O/O_2 makes things more complex
3) In 1997, stricter O_3 standards were challenged in court, but the EPA won.

The EPA determined that the one-hour ozone standard of 0.12 ppm in effect since the late 1970s did not adequately protect the public from adverse health effects. Health effects occur at levels lower than the one-hour standard and exposure times longer than one hour are of concern. In July 1997, the agency replaced the one-hour standard with an eight-hour standard of 0.08 ppm. Above this level is considered an exceedance.

4) NO_x regulations

a) *Ozone Transport Rule*

CAAA established the Ozone Transport Commission (OTC) to coordinate the development of control plans for ground-level ozone in the Northeast and Mid-Atlantic Regions of the U.S.

b) *CAAA Standards*

Two sets of standards have been defined for light-duty vehicles in the Clean Air Act Amendments of 1990

IX. Coping with Acid Deposition

A. **Title IV of the Clean Air Act Amendments (CAAA) of 1990**

1) goals and purposes

The purpose of Title IV is to reduce the adverse effects of acid deposition through reductions in annual emissions of SO_2 (10,000,000 tons from 1980 emission levels) *and*, in combination with other provisions of this Act, of *NO_x emissions* (approximately 2,000,000 tons from1980 emission levels), *in the 48 contiguous States and the District of Columbia.*

It is the intent to effectuate such reductions by *requiring compliance by affected sources with prescribed emission limitations by specified deadlines*, which limitations may be met through alternative methods of compliance provided by an emission allocation and transfer system.

It is also the purpose of this Title to *encourage energy conservation, use of renewable and clean alternative technologies, and pollution prevention as a long-range strategy,* for reducing air pollution and other adverse impacts of energy production and use.

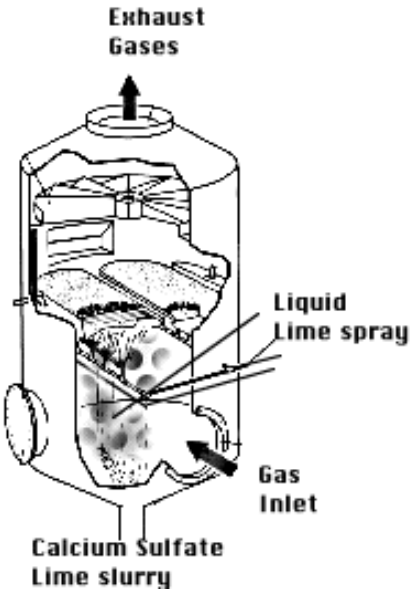
2) uses **emission allowances**, not command and control
(1 allowance = 1 ton SO_2)
3) positive outcomes
   a) utilities switching to *low-S coal*
      - Low sulfur coal (0-1% sulfur) is surface mined in the Western states of Wyoming and Montana
      - High sulfur coal (2-4% sulfur) is currently mined in the Midwestern states of Illinois, Indiana, Ohio, West Virginia, and Kentucky
   b) utilities are *trading emission allowances*
   c) older power plants are installing **scrubbers** (see diagram, next page) from http://www.elmhurst.edu/~chm/vchembook/197acidrainsoln.html

"Scrubbers remove 80-95 % of the SO_x. Certain types do not remove NO_x. They are costly to retrofit to existing power plants. They increase the electric generating costs by 10-15 %.

Scrubbers are like 'liquid' filters for the gases resulting from combustion. The exhaust gases are forced through a spray of water containing calcium hydroxide, $Ca(OH)_2$. The SO_2 gas reacts with

the lime to produce a solid of calcium sulfate, $CaSO_4$. There are then problems in getting rid of the liquid sludge that is produced. It can be pumped into a pond for temporary storage."

DIAGRAM OF A SCRUBBER



X. Unresolved Issues

A. Costs vs. benefits

B. EPA's **New Source Review**

from http://www.epa.gov/nsr/

"Congress established the New Source Review (NSR) permitting program as part of the 1977 Clean Air Act Amendments. NSR is a preconstruction permitting program that serves two important purposes.

First, it ensures that air quality is not significantly degraded from the addition of new and modified factories, industrial boilers and power plants. In areas with unhealthy air, NSR assures that new emissions do not slow progress toward cleaner air. In areas with clean air, especially pristine areas like national parks, NSR assures that new emissions do not significantly worsen air quality.

Second, the NSR program assures people that any large new or modified industrial source in their neighborhoods will be as clean as possible, and that advances in pollution control occur concurrently with industrial expansion."

C. **Clear Skies Act of 2003**
http://www.epa.gov/clearskies/CSA2003shortsummary2_27_03_final.pdf

a) amended Title IV of the Clean Air Act
b) addresses SO_x, NO_x, and Hg
c) Cut sulfur dioxide (SO_2) emissions by 73 % - from year 2000 emissions of 11,000,000 tons to a cap of 4,500,000 tons in 2010 and to a cap of 3,000,000 tons in 2018.
d) Cut emissions of nitrogen oxides (NO_x) by 67 %, from year 2000 emissions of 5,000,000 tons to a cap of 2,100,000 tons in 2008 and to a cap of 1,700,000 million tons in 2018.

e) Cut mercury emissions by 69 % - the first-ever national cap on mercury emissions. Emissions would be cut from 1999 emissions of 48 tons to a cap of 26 tons in 2010 and to a cap of 15 tons in 2018.

D. Getting Around
   1) higher CAFE standards are fought by automakers, fossil fuel industry, and various politicians
   2) gasoline-electric hybrid cars are more commonplace than ever