

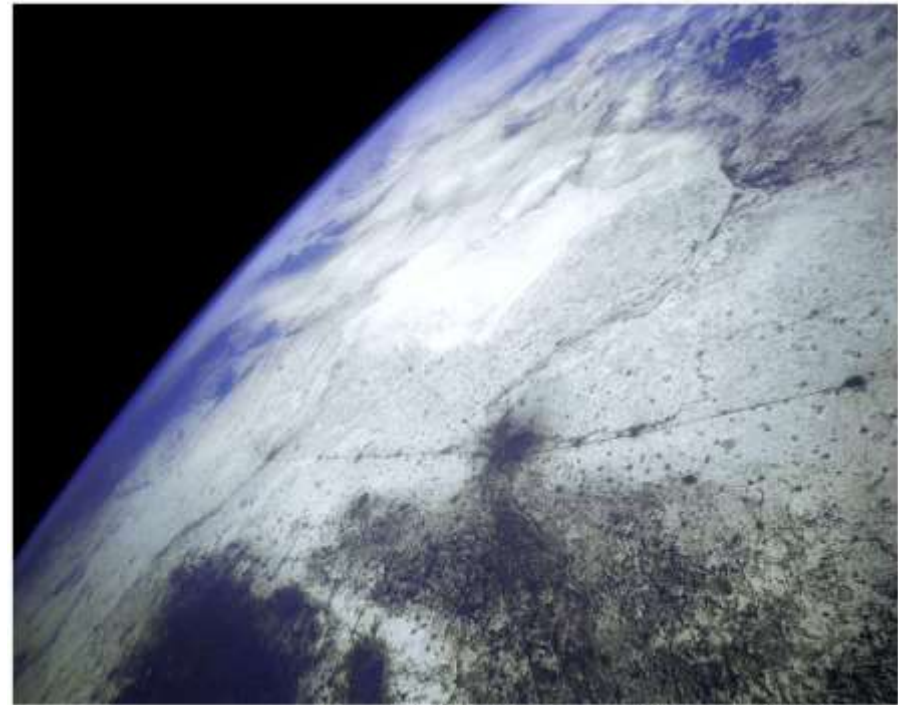
Air Pollution

Overview of Chapter

- Atmosphere as a Resource
- Types and Sources of Air Pollution
 - Major Classes of Air Pollutants
 - Sources of Outdoor Air Pollutants
 - Urban Air Pollution
- Effects of Air Pollution
- Controlling Air Pollution

Atmosphere as a Resource

- Atmospheric Composition
 - Nitrogen 78.08%
 - Oxygen 20.95%
 - Argon 0.93%
 - Carbon dioxide 0.04%
- Ecosystem services
 - Blocks UV radiation
 - Moderates the climate
 - Redistributes water in the hydrologic cycle



Types and Sources of Air Pollution

- Air Pollution
 - Chemicals added to the atmosphere by natural events or human activities in high enough concentrations to be harmful
- Two categories
 - Primary Air Pollutant
 - Harmful substance that is emitted directly into the atmosphere
 - Secondary Air Pollutant
 - Harmful substance formed in the atmosphere when a primary air pollutant reacts with substances normally found in the atmosphere or with other air pollutants

Major Air Pollutants

Table 20.1 Major Air Pollutants

<i>Pollutant</i>	<i>Composition</i>	<i>Primary or Secondary</i>	<i>Characteristics</i>
<i>Particulate matter</i>			
Dust	Variable	Primary	Solid particles
Lead	Pb	Primary	Solid particles
Sulfuric acid	H ₂ SO ₄	Secondary	Liquid droplets
<i>Nitrogen oxides</i>			
Nitrogen dioxide	NO ₂	Primary	Reddish-brown gas
<i>Sulfur oxides</i>			
Sulfur dioxide	SO ₂	Primary	Colorless gas with strong odor
<i>Carbon oxides</i>			
Carbon monoxide	CO	Primary	Colorless, odorless gas
Carbon dioxide*	CO ₂	Primary	Colorless, odorless gas
<i>Hydrocarbons</i>			
Methane	CH ₄	Primary	Colorless, odorless gas
Benzene	C ₆ H ₆	Primary	Liquid with sweet smell
<i>Ozone</i>	O ₃	Secondary	Pale blue gas with acrid odor
<i>Air toxics</i>			
Chlorine	Cl ₂	Primary	Yellow-green gas

* Discussed in Chapter 21.

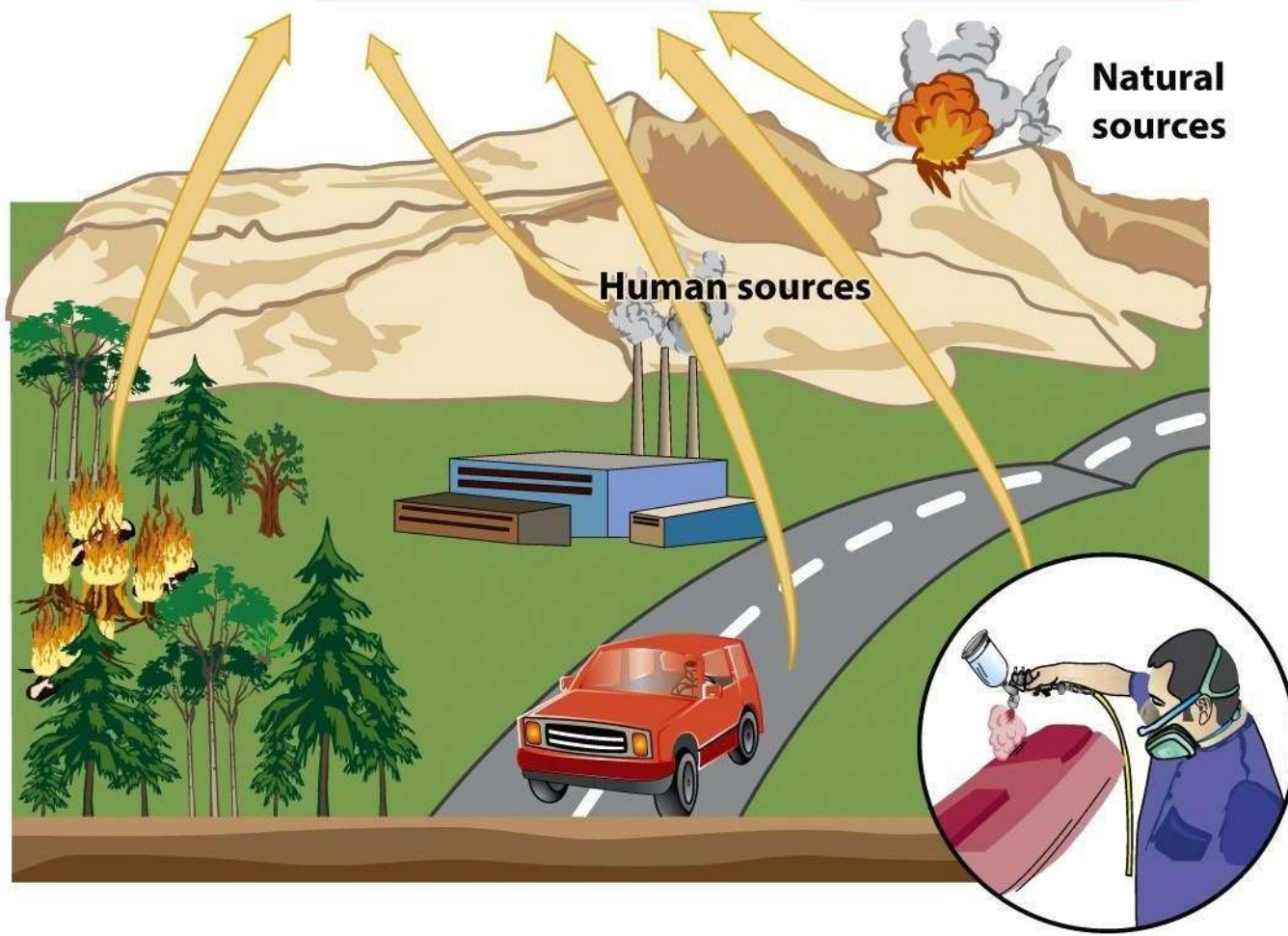
Source: Environmental Protection Agency.

Primary air pollutants

CO CO₂
SO₂ NO NO₂
Most hydrocarbons
Most particulates

Secondary air pollutants

HNO₂ SO₃
HNO₃ H₂SO₄
H₂O₂ O₃ PANs
Most NO₃⁻ and SO₄²⁻
salts



Major Classes of Air Pollutants

- Particulate
Material
- Nitrogen Oxides
- Sulfur Oxides
- Carbon Oxides
- Hydrocarbons
- Ozone

Nitrogen and Sulfur Oxides

- Nitrogen Oxides
 - Gases produced by the chemical interactions between atmospheric nitrogen and oxygen at high temperature
 - Problems
 - Greenhouse gases
 - Cause difficulty breathing
- Sulfur Oxides
 - Gases produced by the chemical interactions between sulfur and oxygen
 - Causes acid precipitation

Sulphur Oxides (SO_x)

- **Properties:** Gas, colorless and odorless in low concentrations, but with irritating odor in high concentrations
- **Sources:** Power plants, oil refineries, chemical plants, paper industry, ships' main and auxiliary engines
- **Sulphur content in crude oil and fuel oils**
 - a) Safety (installation and piping corrosion, poison potential)
 - b) Operation (fluidized beds of catalysts may be contaminated from the presence of sulphur compounds)
 - c) Environment (SO_x emissions)



Sulphur Oxides (SO_x)

Impacts to human health

- Short term exposure in high concentrations, might cause bronchoconstriction and increased asthma symptoms.
- Long term exposure might cause serious respiratory problems and deteriorate existing cardiovascular illnesses



4.000 people were fatally exposed to high SO_x and smoke concentrations in London (1952)

Sulphur Oxides (SO_x)

Environmental impacts

Acid rain

- In the 70s, more than 18,000 lakes in Sweden were found with acidity exceeding the natural limits, and in half of them fish populations had dramatically reduced
- The same phenomenon occurred in about 3,000 lakes in US
- The transformation of the waters of a lake to acidic does not take place instantaneously but rather in a period of many years or decades.



A forest in Jizera, Czech Republic

Sulphur Oxides (SO_x)

Acid rain formation mechanism

- H₂SO₄ and HNO₃ are formed as a result of the reaction between the water and sulphur as well as nitrogen oxides with the sun radiation and oxygen as catalysts
- Normal rain is slightly acidic (pH 5,5) due to CO₂ dissolution and H₂CO₃ formation
- Most lakes have a pH ranging from 6 to 8. Values as low as 4.3 have been reported in several lakes facing acid rain problems

Sulphur Oxides (SO_x)

Impacts of acid rain

- Destruction of sensitive soils, trees and vegetation of forests in high altitudes
- Deterioration of materials and paints. Irreversible failures to buildings and monuments that constitute elements of cultural heritage
- Impacts to water dependent ecosystems

Nitrogen Oxides (NO_x)

NO_x formation in ship's engines

- Very complex mechanism of formation, hundreds of chemical reactions occur
- Main source of nitrogen is air combustion
- Higher temperatures in cylinders lead to increase NO_x emissions
- 95% is NO and about 5% NO₂



Nitrogen Oxides (NO_x)

- Impacts to human health

They react with hemoglobin producing inert compounds including methemoglobin hampering the oxygenation of tissues causing tachycardia, high blood pressure, and arrhythmia

> 15 $\mu\text{g}/\text{m}^3$, irritation of the eyes

> 25 $\mu\text{g}/\text{m}^3$ dyspnea, asthma crisis

> 150 – 200 $\mu\text{g}/\text{m}^3$ pulmonary edema



Nitrogen Oxides (NO_x)

Secondary ozone formation



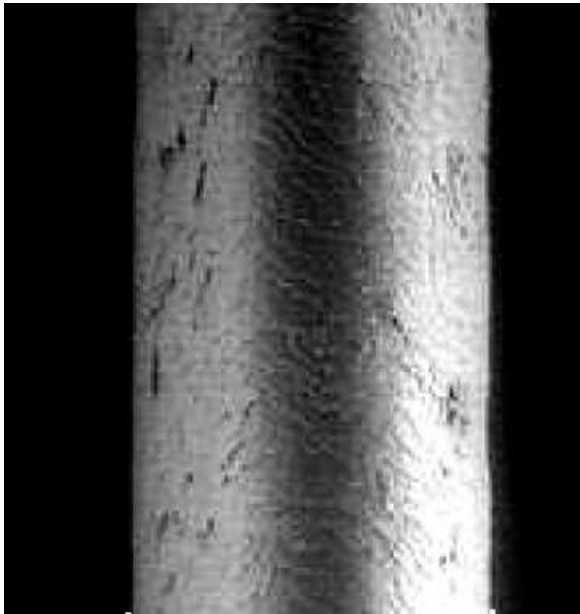
Photochemical smog occurs in sunny periods with high temperatures, low moisture and relatively high levels of nitrogen oxides and hydrocarbons.

Particulate Material

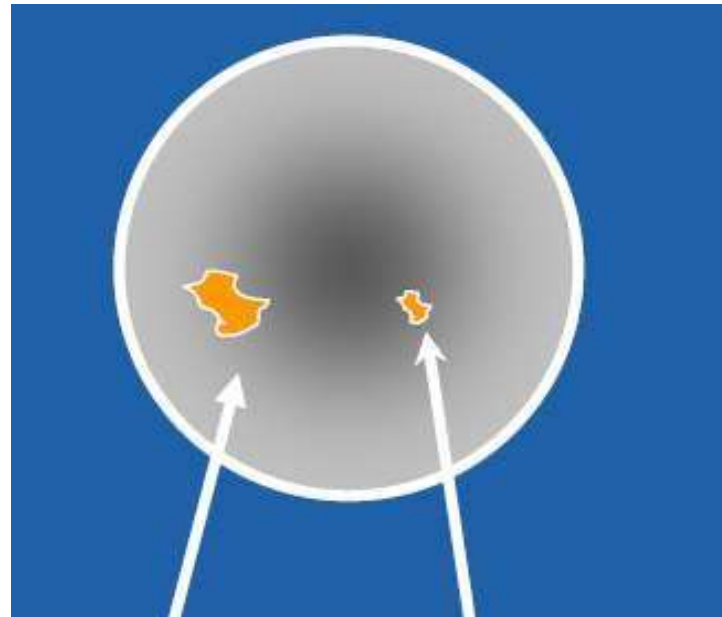
- Thousands of different solid or liquid particles suspended in air
 - Includes: soil particles, soot, lead, asbestos, sea salt, and sulfuric acid droplets
- Dangerous for 2 reasons
 - May contain materials with toxic or carcinogenic effects
 - Extremely small particles can become lodged in lungs

Particulate matter (PM)

Particles produced during combustion or as secondary products in the atmosphere, that might shift for very long periods far from their point of source.



Human hair
(70 μm diameter)



PM 10
(10 μm)

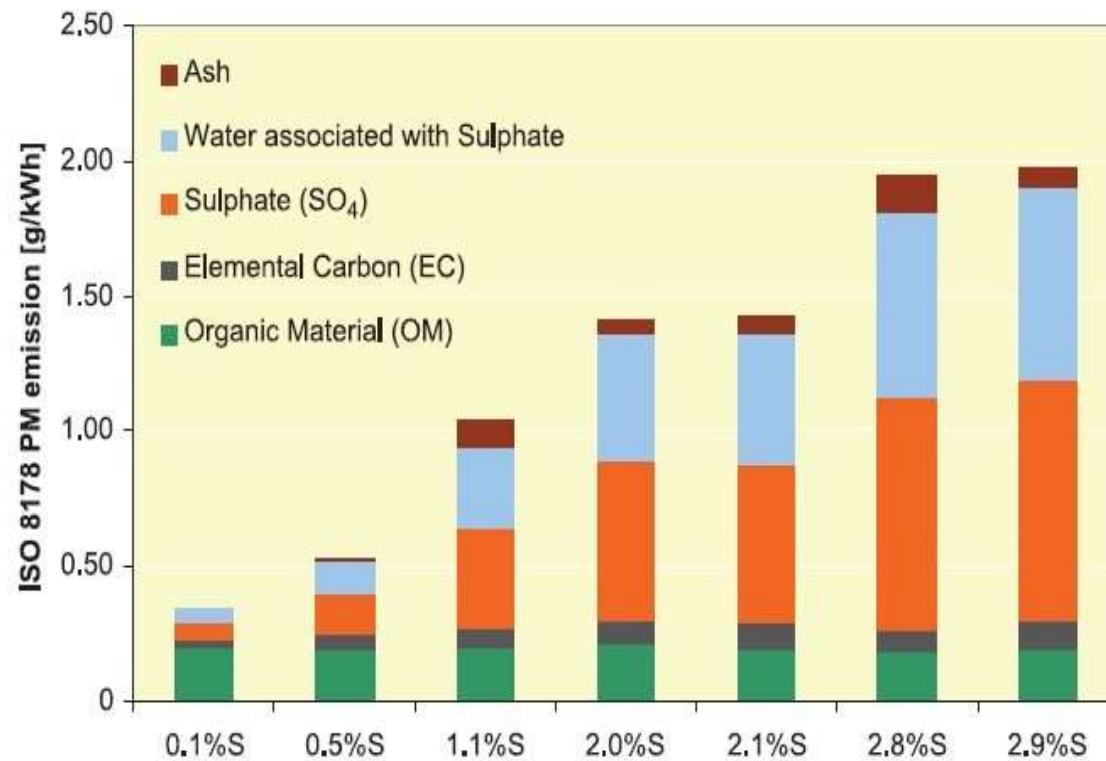
PM 2.5
(2,5 μm)

Particulate matter (PM)

- Their chemical composition depends on fuel quality. They invariably consist of soot, hydrocarbons, ash, metals (vanadium, nickel, zinc), sulphur and nitrate compounds
- The smaller the size of the particles, the deeper penetrate into the human respiratory system.



Particulate matter (PM)

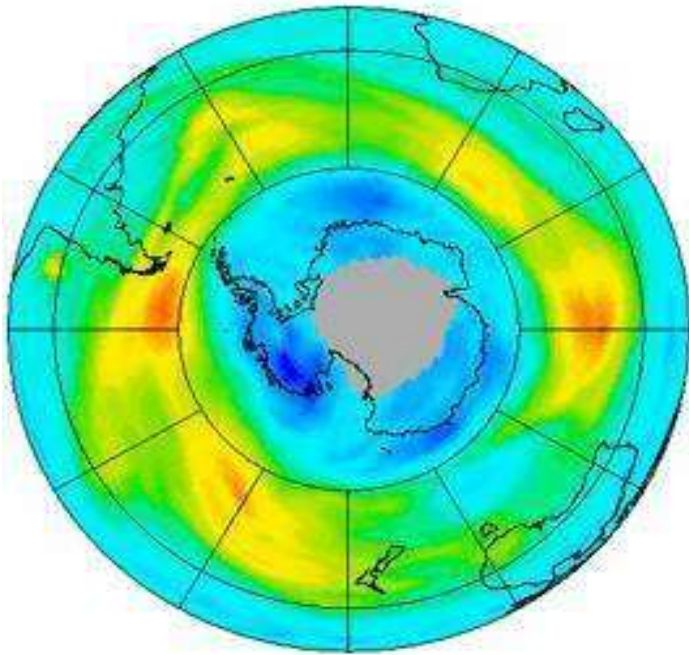


- Ash significantly reduced for low sulphur fuel oils (< 1% m/m).
- Soot and sulfates are directly depended on the sulfur content.

Ozone

- Tropospheric Ozone
 - Man- made pollutant in the lower atmosphere
 - Secondary air pollutant
 - Component of photochemical smog
- Stratospheric Ozone
 - Essential component that screens out UV radiation in the upper atmosphere
 - Man- made pollutants (ex: CFCs) can destroy it

Ozone Depleting Substances (ODS)



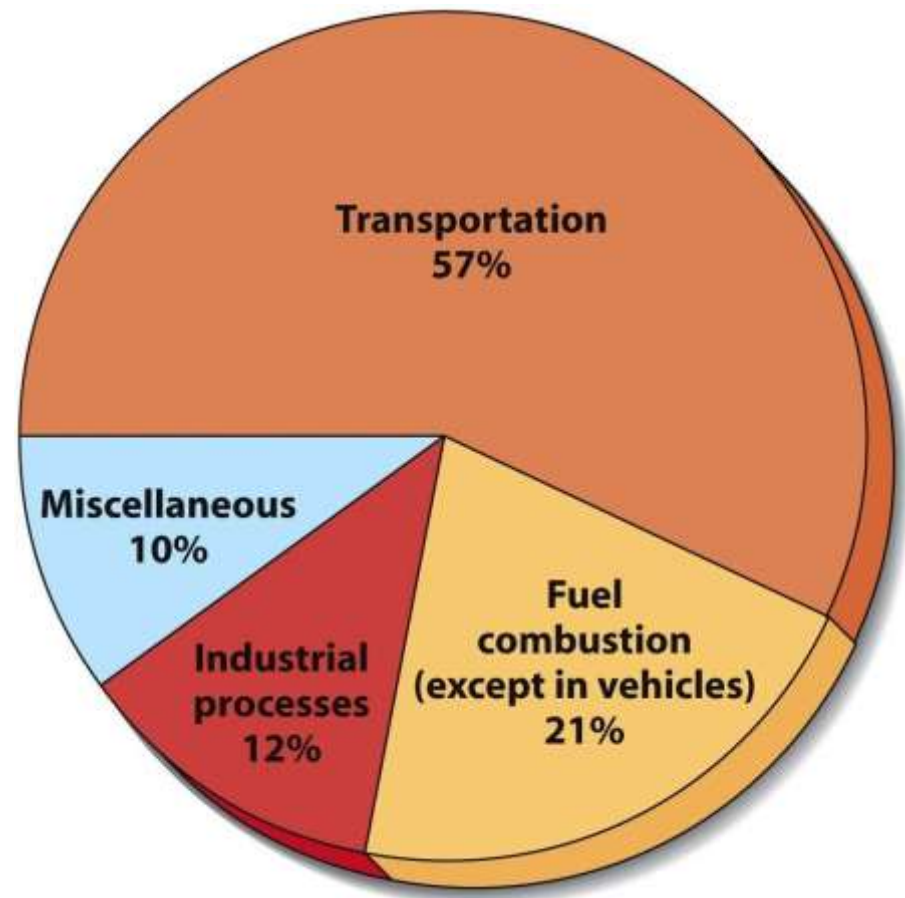
- Lifetime of gases in atmosphere from several years (HCFCs) until a century (Freon 12).
- The ozone layer is going to be back to the level it was before 1980 until 2050.
- If ozone was compressed in normal conditions of temperature and pressure, it would have been less than 5 mm thick.
- In September 2007, the extent of ozone hole was 24 million km² (almost as North America), 18% smaller in relation to 2006.

Carbon Oxides and Hydrocarbons

- Carbon Oxides
 - Gases carbon monoxide (CO) and carbon dioxide (CO₂)
 - Greenhouse gases
- Hydrocarbons
 - Diverse group of organic compounds that contain only hydrogen and carbon (ex: CH₄- methane)
 - Some are related to photochemical smog and greenhouse gases

Sources of Outdoor Air Pollution

- Two main sources
 - Transportation
 - Industry
- Intentional forest fires is also high

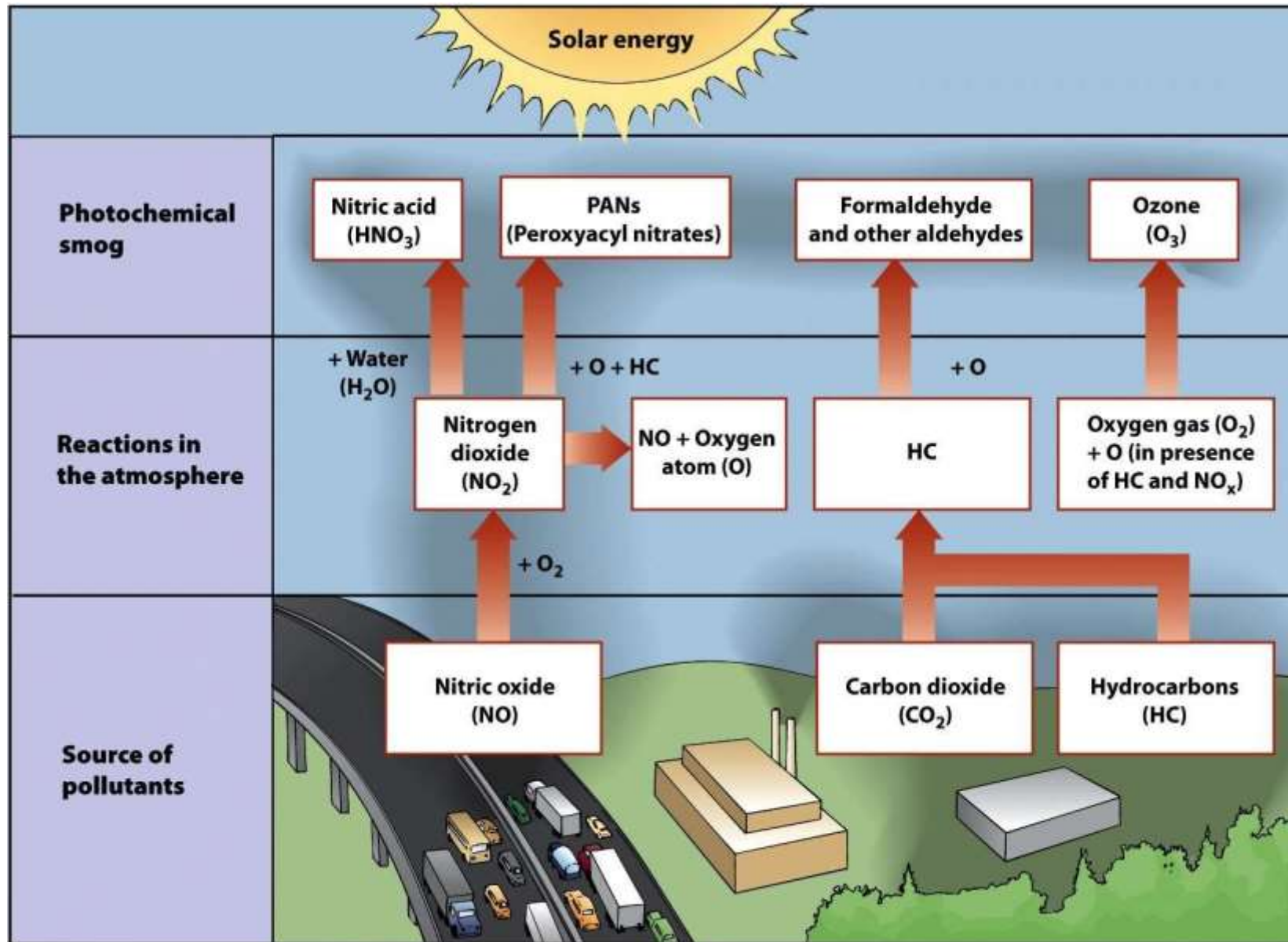


Urban Air Pollution

- Photochemical Smog
- Brownish-orange haze formed by chemical reactions involving sunlight, nitrogen oxide, and hydrocarbons



Formation of Photochemical Smog



Case-In-Point Air Pollution in Beijing and Mexico City



- Beijing (left)
- Mexico City (above)

Effects of Air Pollution

- Low level exposure
 - Irritates eyes
 - Causes inflammation of respiratory tract
- Can develop into chronic respiratory diseases

Table 20.2 Health Effects of Several Major Air Pollutants		
<i>Pollutant</i>	<i>Source</i>	<i>Effects</i>
Particulate	Industries, electric power plants, motor vehicles, construction, agriculture	Aggravates respiratory illnesses; long-term exposure may cause increased incidence of chronic conditions such as bronchitis; linked to heart disease; suppresses immune system; some particles, such as heavy metals and organic chemicals, may cause cancer or other tissue damage
Nitrogen oxides	Motor vehicles, industries, heavily fertilized farmland	Irritate respiratory tract; aggravate respiratory conditions such as asthma and chronic bronchitis
Sulfur oxides	Electric power plants and other industries	Irritate respiratory tract; same effects as particulates
Carbon monoxide	Motor vehicles, industries, fireplaces	Reduces blood's ability to transport oxygen; headache and fatigue at lower levels; mental impairment or death at high levels
Ozone	Formed in atmosphere (secondary air pollutant)	Irritates eyes; irritates respiratory tract; produces chest discomfort; aggravates respiratory conditions such as asthma and chronic bronchitis

Health Effects of Air Pollution

- Sulfur Dioxide and Particulate material
 - Irritate respiratory tract and impair ability of lungs to exchange gases
- Nitrogen Dioxides
 - Causes airway restriction
- Carbon monoxide
 - Binds with iron in blood hemoglobin
 - Causes headache, fatigue, drowsiness, death
- Ozone
 - Causes burning eyes, coughing, and chest discomfort

Children and Air Pollution

- Greater health threat to children than adults
 - Air pollution can restrict lung development
 - Children breath more often than adults
- Children who live in high ozone areas are more likely to develop asthma

Controlling Air Pollution

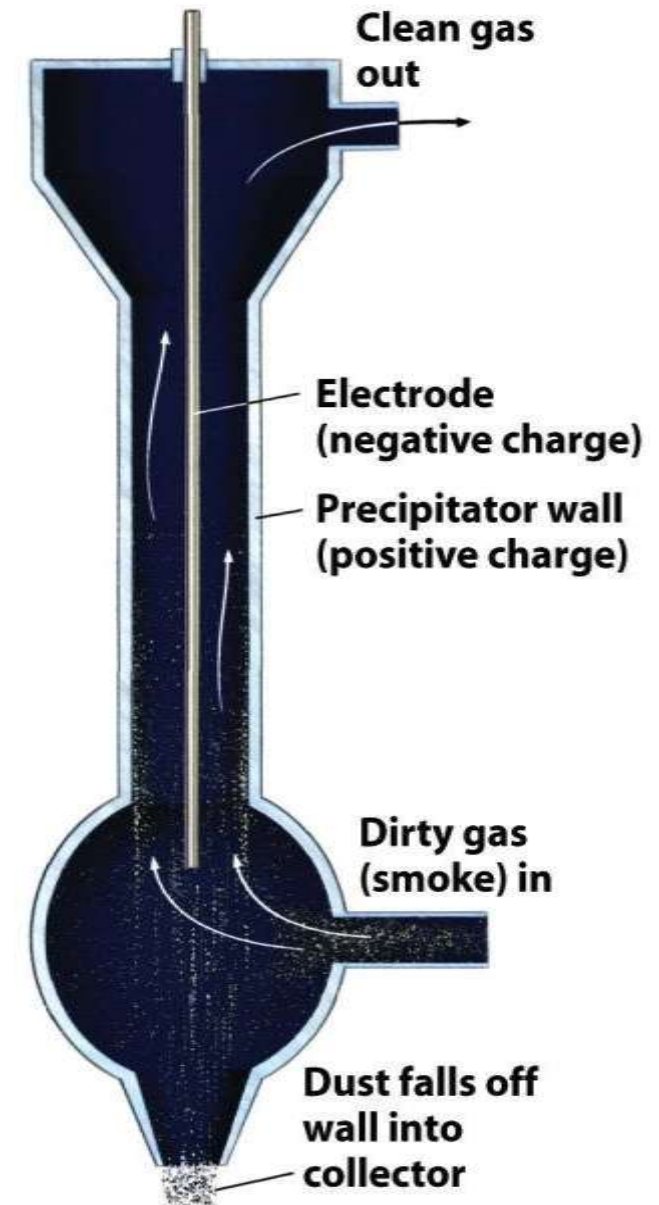
- Smokestacks with electrostatic precipitator (right)



Without
Electrostatic
precipitator

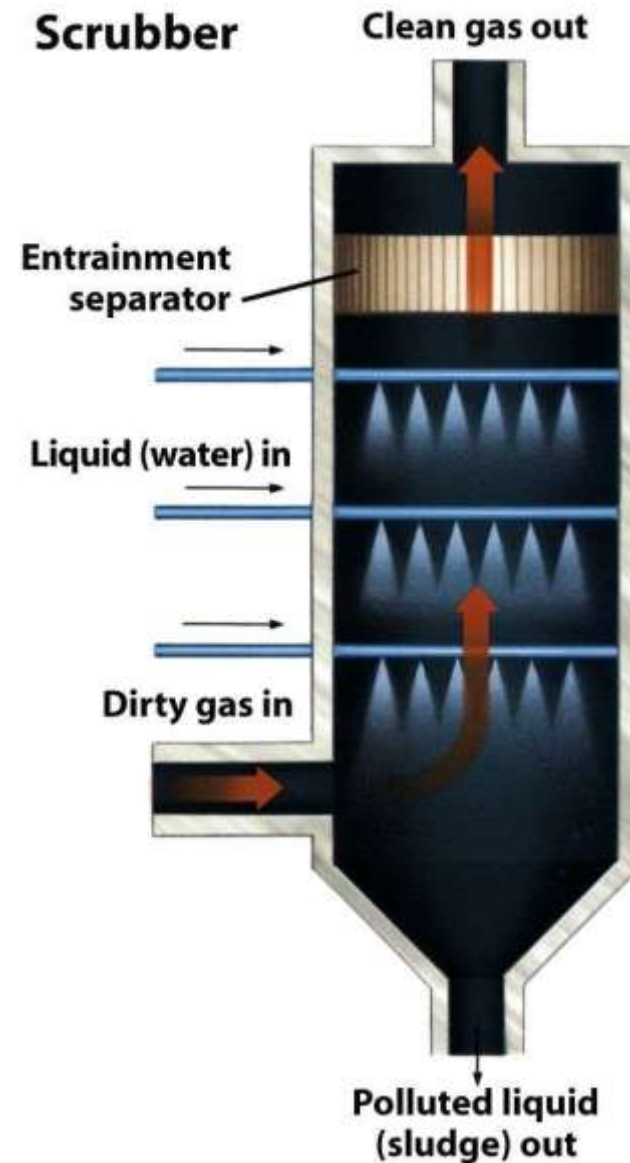
With
Electrostatic
precipitator

Electrostatic precipitator



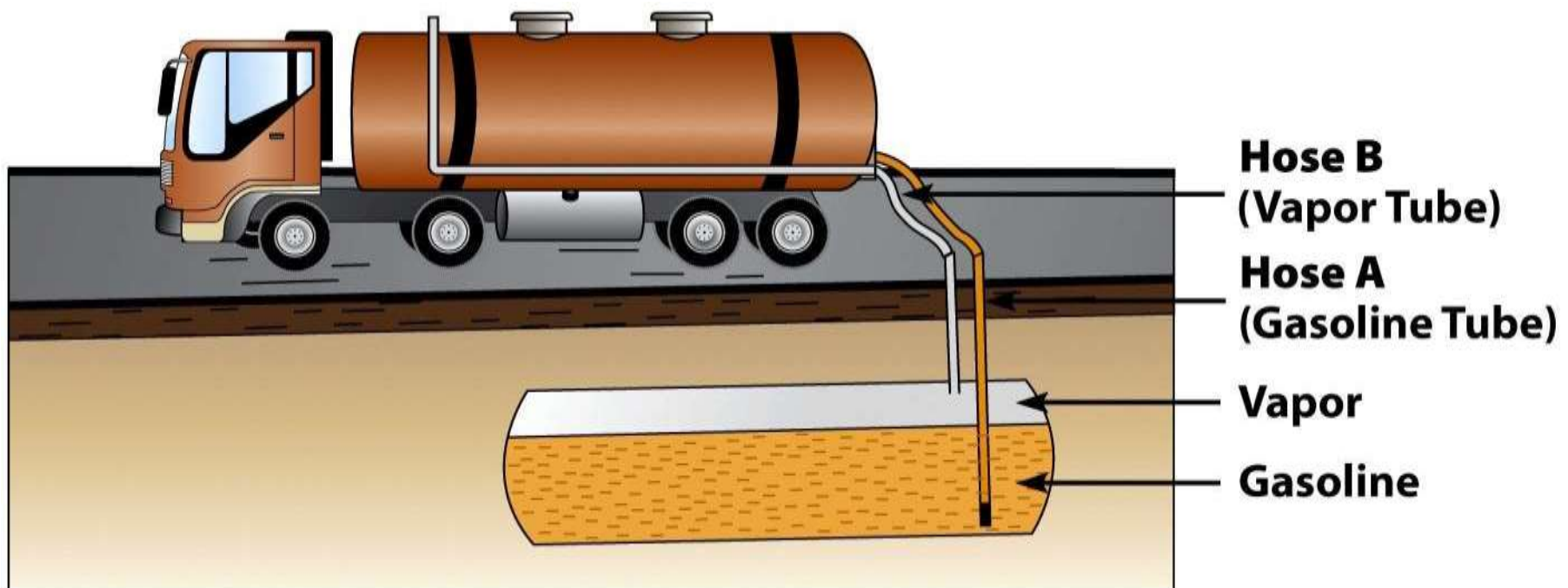
Controlling Air Pollution

- Smokestacks with scrubbers (right)
- Particulate material can also be controlled by proper excavating techniques



Controlling Air Pollution

- Phase I Vapor Recovery System for gasoline

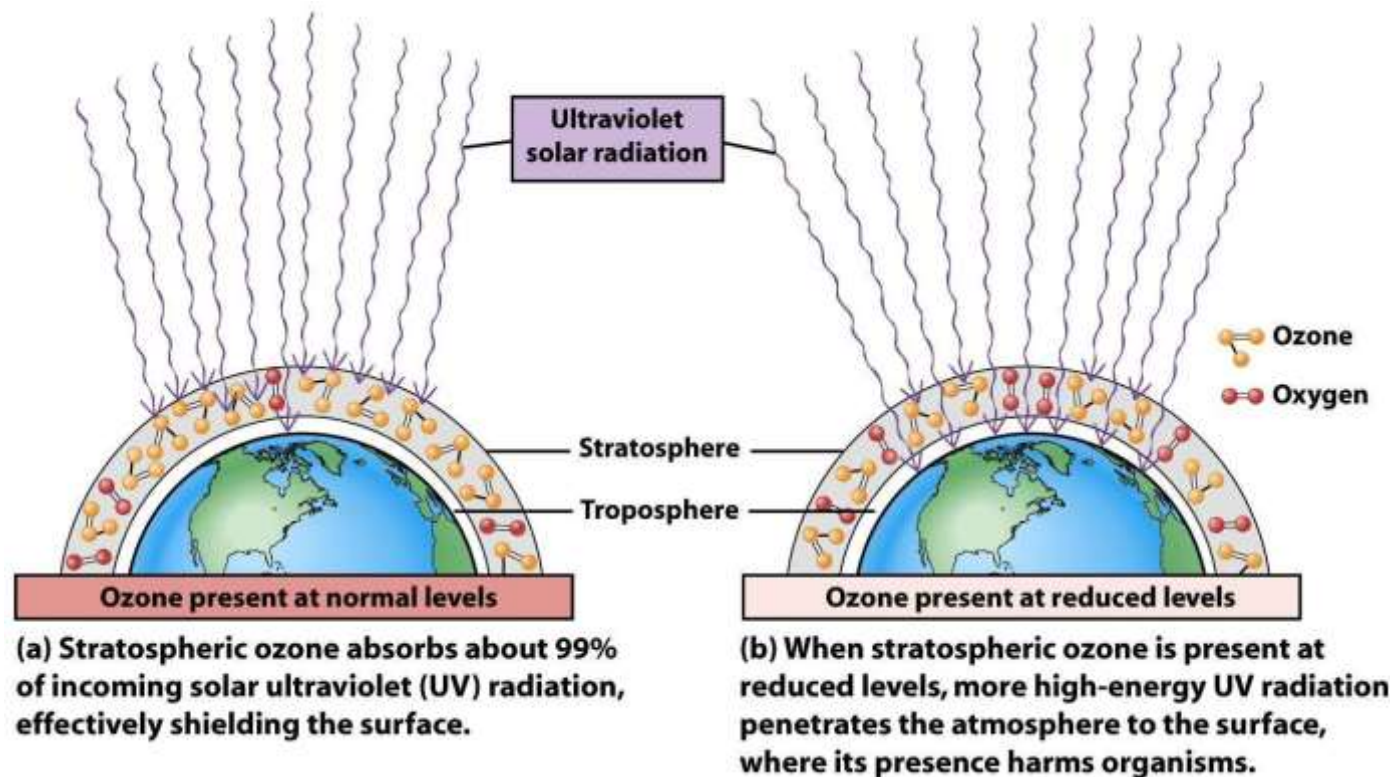


Other Ways to Improve Air Quality

- Reduce sulfur content in gasoline
 - Sulfur clogs catalytic converters
- Require federal emission standards for all passenger vehicles
 - Including SUVs, trucks and minivans
- Require emission testing for all vehicles
 - Including diesel

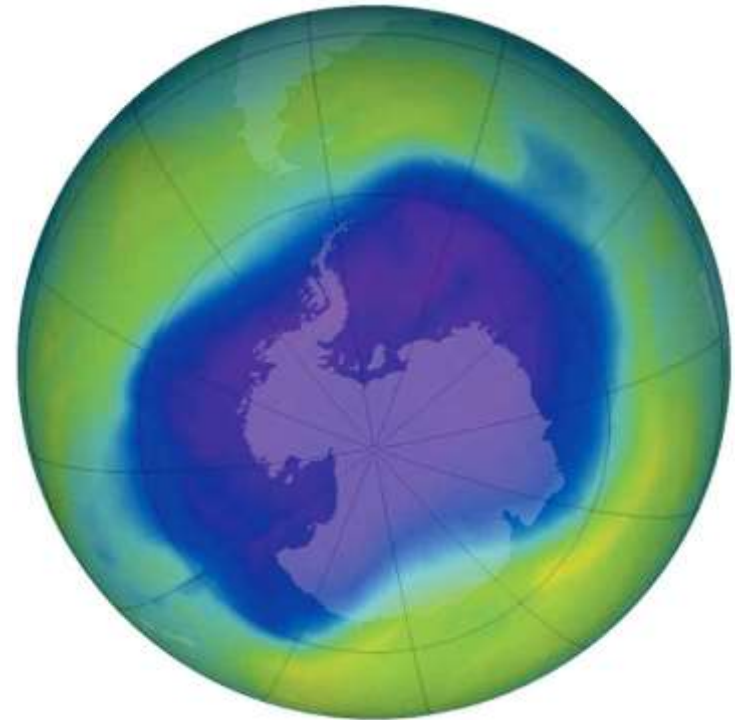
Ozone Depletion in Stratosphere

- Ozone Protects earth from UV radiation
 - Part of the electromagnetic spectrum with wavelengths just shorter than visible light



Ozone Depletion in Stratosphere

- Ozone thinning/hole
 - First identified in 1985 over Antarctica
- Caused by
 - human-produced bromine and chlorine containing chemicals
 - Ex: CFCs



Ozone Depletion in Stratosphere

- Hole over Antarctica requires two conditions:
 - Sunlight just returning to polar region
 - Circumpolar vortex- a mass of cold air that circulates around the southern polar region
 - Isolates it from the warmer air in the rest of the planet
- Polar stratospheric clouds form
 - Enables Cl and Br to destroy ozone

Effects of Ozone Depletion

- Higher levels of UV-radiation hitting the earth
 - Eye cataracts
 - Skin cancer (right)
 - Weakened immunity
- May disrupt ecosystems
- May damage crops and forests

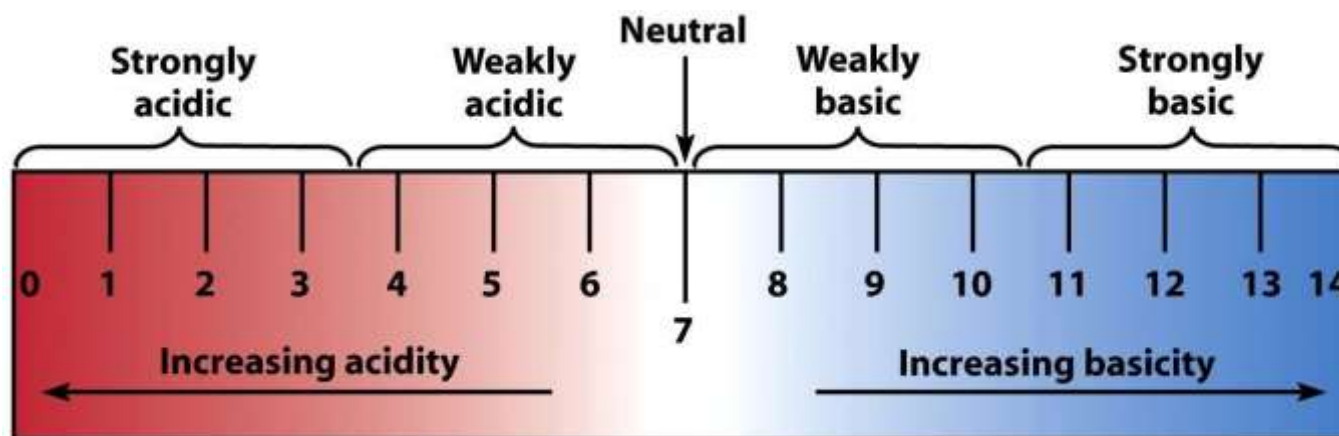


Recovery of Ozone Layer

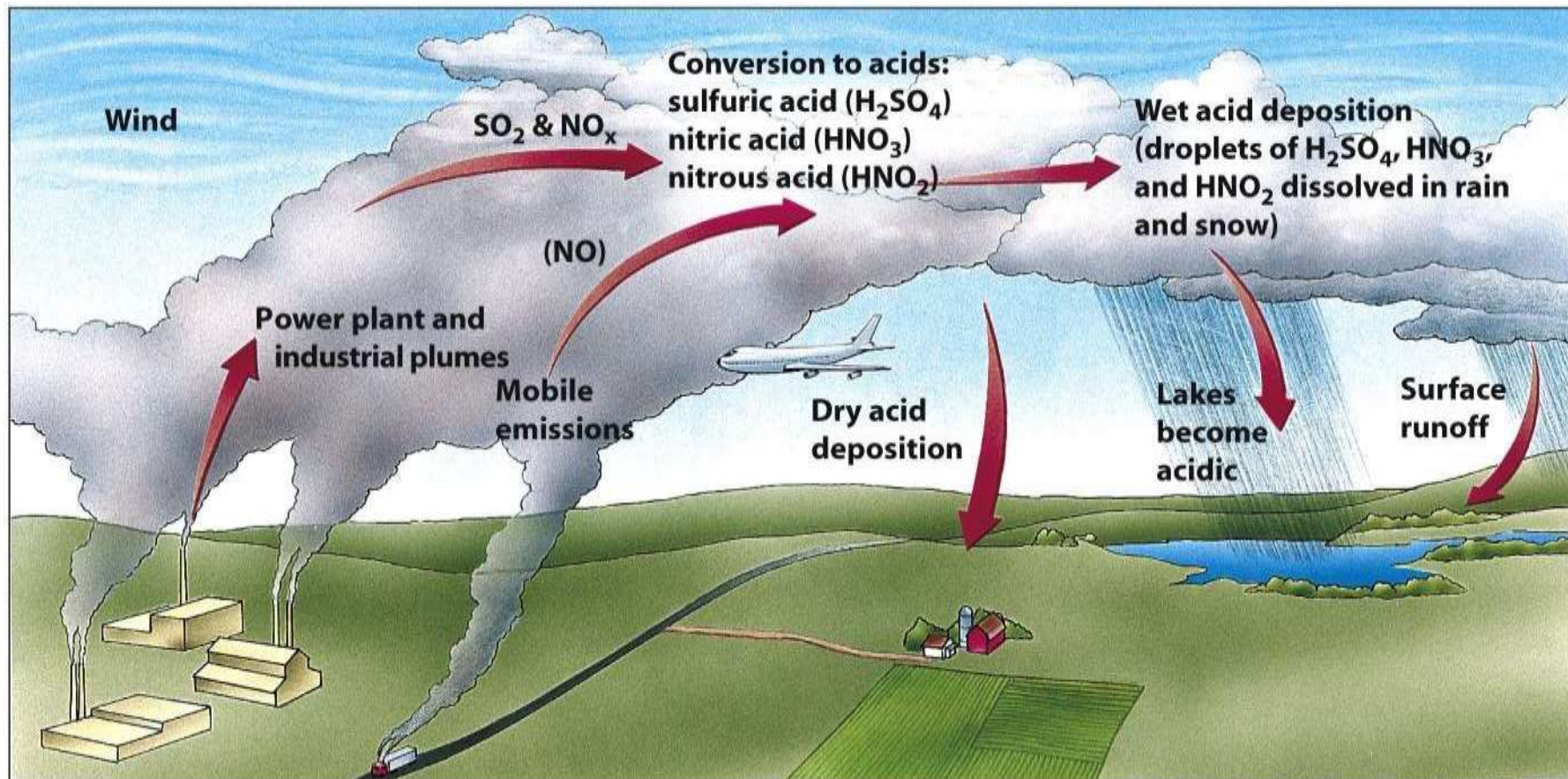
- Montreal Protocol (1987)
 - Reduction of CFCs
 - Started using HCFCs (greenhouse gas)
- Phase out of all ozone destroying chemicals is underway globally
- Satellite pictures in 2000 indicated that ozone layer was recovering
- Full recovery will not occur until 2050

Acid Deposition

- Sulfur dioxide and nitrogen dioxide emissions react with water vapor in the atmosphere and form acids that return to the surface as either dry or wet deposition
- pH scale



How Acid Deposition Develops

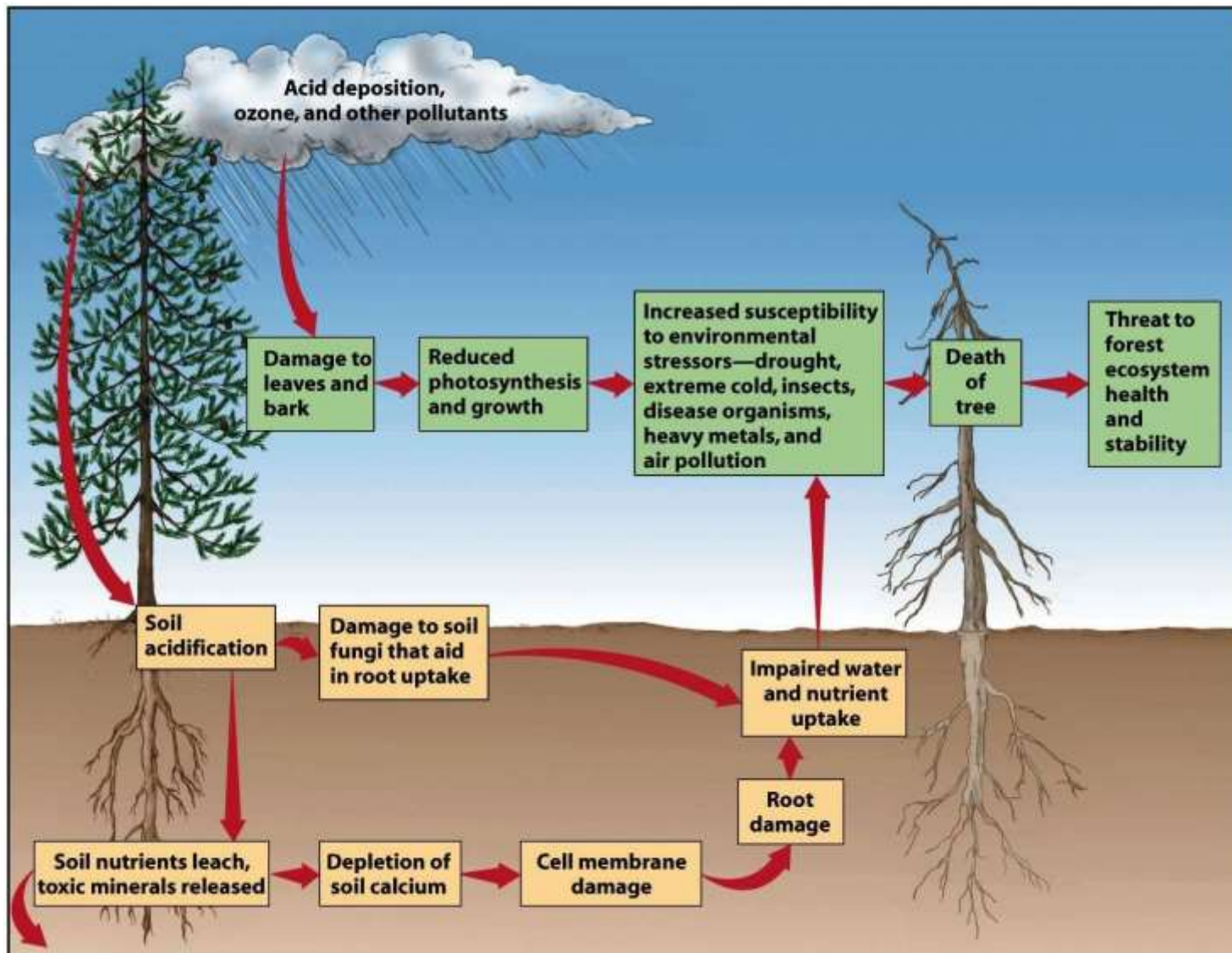


Effects of Acid Deposition

- Declining Aquatic Animal Populations
- Thin-shelled eggs prevent bird reproduction
 - Because calcium is unavailable in acidic soil
- Forest decline
 - Ex: Black forest in Germany (50% is destroyed)



Acid Deposition and Forest Decline

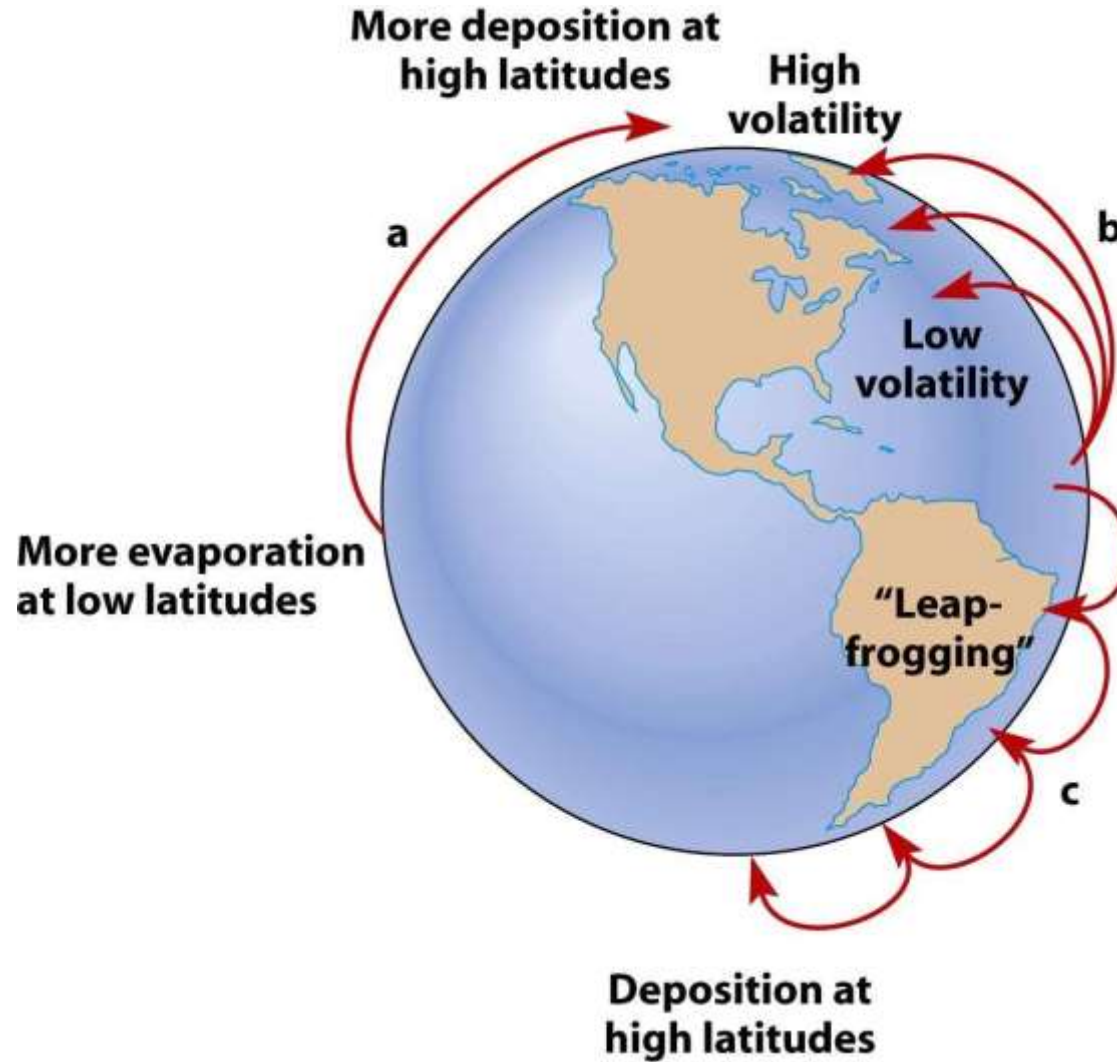


Air Pollution Around the World



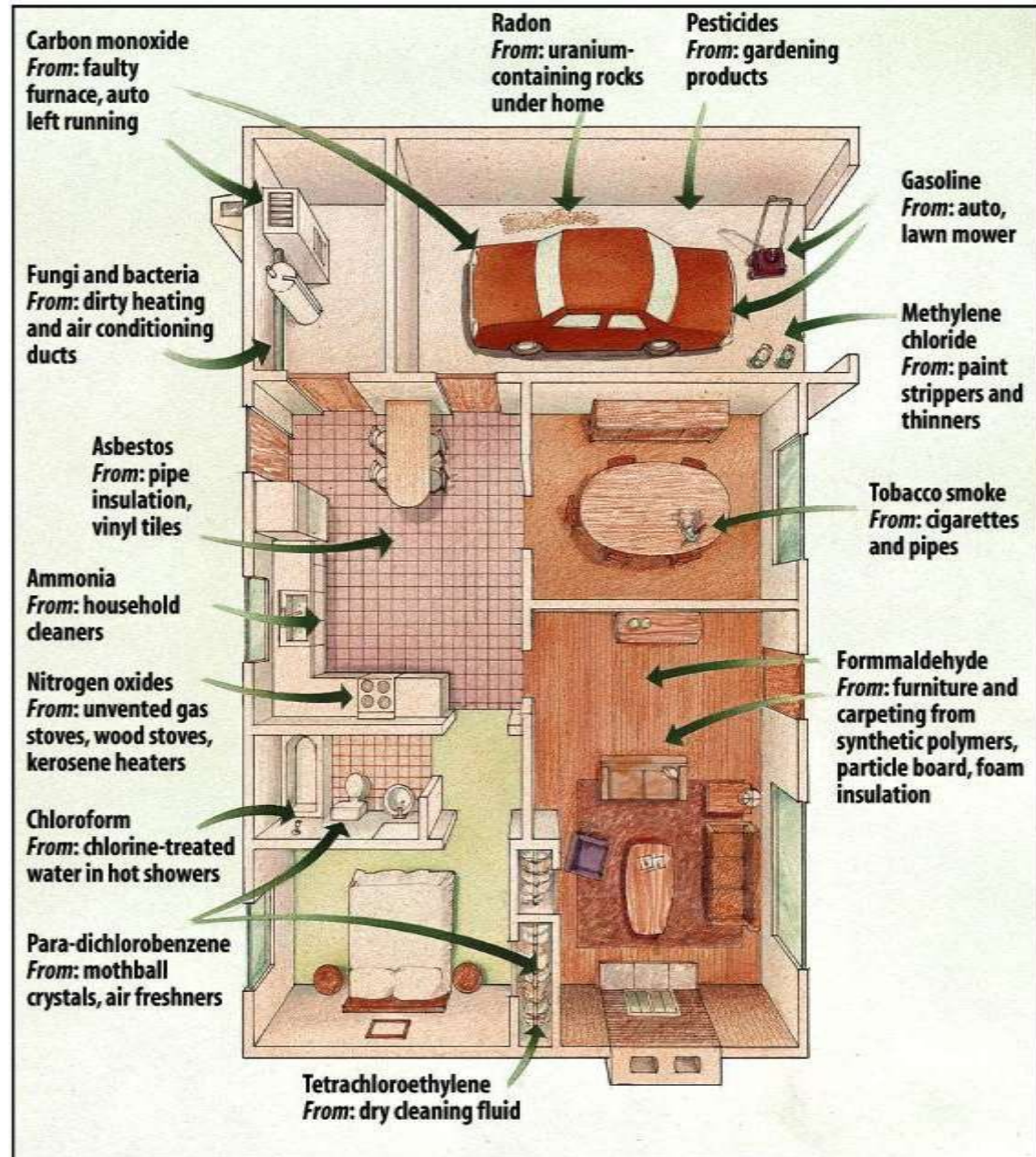
- Air quality is deteriorating rapidly in developing countries
- Shenyang, China
 - Residents only see sunlight a few weeks each year
- Developing countries have older cars
 - Still use leaded gasoline
- 5 worst cities in world
 - Beijing, China; Mexico City, Mexico; Shanghai, China; Tehran, Iran; and Delhi, India

Long Distance Transport of Air Pollutants



Indoor Air Pollution

- Pollutants can be 5- 100X greater than outdoors
- Most common:
 - Radon, cigarette smoke, carbon monoxide, nitrogen dioxide, formaldehyde pesticides, lead, cleaning solvents, ozone, and asbestos



Indoor Air Pollution - Radon

Radon is a naturally occurring radioactive gas which may be found in **indoore**nvironments such as homes, schools, and workplaces. **Radon** is the most important cause of lung cancer after smoking.

