ATM S 212
Air Pollution: From Urban Smog to the Ozone Hole

Instructor: Professor Becky Alexander
Office hours: M and Th 11:30-12:30 in 306 ATG
Required textbook: "*Earth Under Siege*" by Richard Turco

Course description:

This course is an introduction to air pollution on local, regional and global scales. We will focus on the sources, transformation, and dispersion of pollutants responsible for urban smog, acid rain, climate change and the stratospheric ozone hole. We will examine the health and environmental impacts of air pollutants, as well as current (or potential) technological solutions and policy regulations.

Student learning goals

- Understand how emissions, transport, chemistry and deposition impact air pollution.
- Explain the chemical and physical mechanisms behind ozone depletion, air pollution and acid rain
- Develop skills to critically evaluate discussions of air pollution and climate change based on scientific evidence and organized knowledge

The Natural World Credit (from the UW website)

"Courses in this Area focus on the disciplined, scientific study of the natural world. The Area can be divided into three broad categories: the mathematical sciences, the physical sciences, and the biological sciences."

This course will utilize applications of basic math/physical science concepts to Earth science problems. Thus, there will be some math (basic algebra) and science (basic chemistry) involved. I assume you have all had algebra in high school but may need a review, and you may not have taken chemistry. Thus, Friday classes are important!

Grading policy:

Exams (4) 60%
Class participation (15%)
Papers (15%)
Poster presentation (10%)

How to do well in this class:

- Attend lectures and ask questions. Read the textbook for supplemental information.
- Attempt practice problems in advance and come to practice problem solving sessions on Fridays.
- Get started early on your final project.
- Discuss project topic with the instructor before beginning your final project.

Class Web Site:

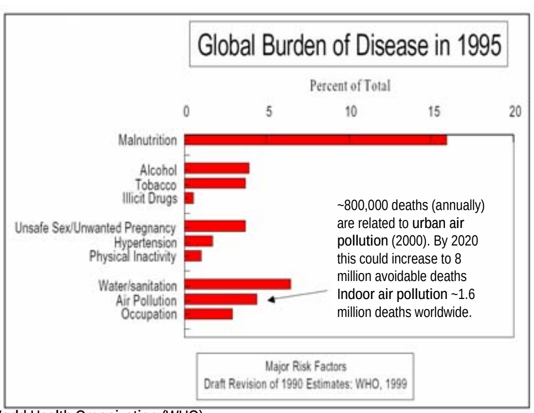
http://www.atmos.washington.edu/academics/classes/2011Q1/212/

Class Policies

- Late assignments (papers and posters) or exams are accepted only with at least 24 hours advanced OK from the instructor (me).
- If you miss class, copy notes from a classmate. Lecture slides are available on the class web site.
- If you feel your exam was graded incorrectly, you must submit your complaint to the instructor in writing, along with your graded exam, no earlier than 24 hours, but no later than one week, after your graded exam is returned to you. Your entire exam will be re-graded.
- Questions about lectures, homework or exams should be directed to the on-line message board. Only email me for personal reasons.
- Bring a calculator to class!

Important dates

- In class exams: Fridays Jan. 14, Jan. 28, Feb. 11, and Mar. 4
- Final project papers are due on Monday, March 7.
- "W" papers: First draft due on Friday, March 4, final draft due on Friday, March 11.
- There is no class on Monday, Jan. 17 or Monday, Feb. 21 (UW holidays)



World Health Organization (WHO)

http://www.arb.ca.gov/research/health/fs/pm-03fs.pdf

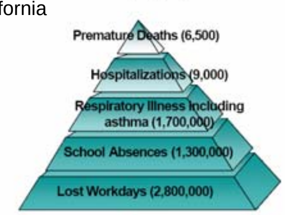
AIR RESOURCES BOARD

AMERICAN LUNG ASSOCIATION of California

Recent Research Findings:
Health Effects of Particulate Matter and Ozone Air Pollution, January 2004

Health Impacts of Air Pollution
(per year)

for California



How close are you willing to live to a freeway?

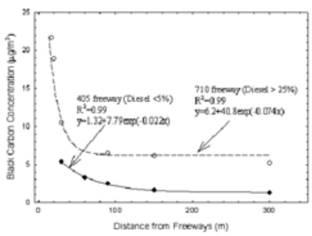
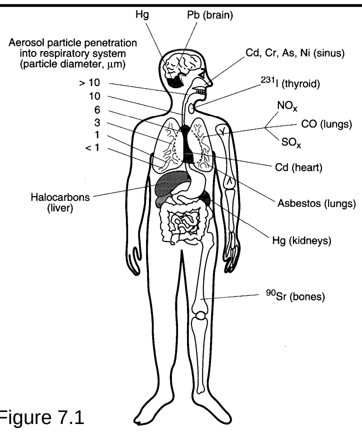


Figure from: The East Bay Children's Respiratory Health Study of Traffic-Related Air Pollution Near Busy Roads

http://www.arb.ca.gov/research/eb-kids/bc-dist.jpg



Turco, Figure 7.1

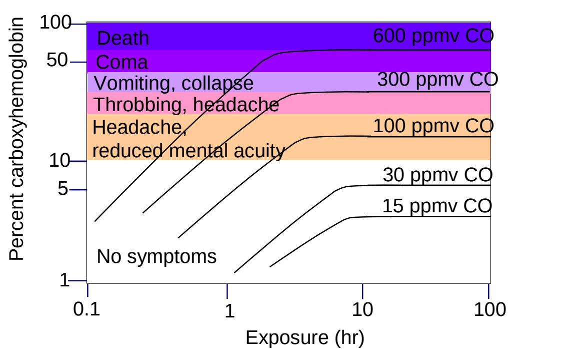
Physiological response of carbon monoxide (CO)

O_2 in air attaches to hemoglobin in the red blood cells.

CO can also attach to hemoglobin forming carboxyhemoglobin (CO-hb)

→ reduces the availability of O_2 to the body

Physiological effects of human exposure to CO



Turco, Table 7.1

Table 7.1 Toxic Heavy Metals

Metal	*Concentration* (ppmm)	*Effects*[a]
Arsenic (As)	0.5	Cancer of the lungs, liver, and skin; teratogenic; poisonous in large doses
Cadmium (Cd)	0.2	Accumulation in the kidneys, lungs, and heart; symptoms like Wilson's disease; 50 ppmm fatal within 1 hour; carcinogenic
Chromium (Cr)	1.0	Skin rashes, lung cancer (after continued exposure); carcinogenic
Iron (Fe)	10.0	Siderosis, or red lung disease
Lead (Pb)	0.15	Brain damage; red blood cell anemia; paralysis of limbs
Manganese (Mn)	5.0	Aching limbs and back; drowsiness; loss of bladder control; nasal bleeding
Mercury (Hg)	0.05	Central nervous system attack; tremors and neuropsychiatric disturbance
Nickel (Ni)	1.0	Skin rashes, cancer of the sinus and lungs (after continued exposure); exposure to 0.001 ppmm of nickel carbonyl leads to nausea, vomiting, and possible death
Vanadium (V)	0.5	Acute spasm of the bronchi; emphysema
Zinc (Zn)	5.0	Fever, muscular pain, nausea, and vomiting

[a]The effects listed correspond to exsposure to the threshold concentrations—in parts per million by mass—given in the table. The exposure is assumed to occur through inhalation of airborne particulates containing the metal, with the amount indicated assumed to be available in a form that may be absorbed into the bloodstream.

Turco, Table 7.2

194 Local and Regional Pollution Issues

Table 7.2 Human Response to Pollutant Exposure

CO	10–30 ppmm	Time distortion (typical urban)
	~100	Throbbing headache (freeways, 100 ppmm)
	300	Vomiting, collapse (tobacco smoke, 400 ppmm)
	600	Death
NO_2	0.06–0.1	Respiratory impact (long-term exposure promotes disease)
	1.5–5.0	Breathing difficulty
	25–100	Acute bronchitits
	150	Death (may be delayed)
O_3	0.02	Odor threshold
	0.1	Nose and throat irritation in sensitive people
	0.3	General nose and throat irritation
	1.0	Airway resistance, headaches
		Long-term exposure leads to premature aging of lung tissue
SO_2	0.3	Taste threshold (acidic)
	0.5	Odor threshold (acrid)
	1.5	Bronchiolar constriction, respiratory infection

Health effects of air pollutants

Pollutant	Effects related to short-term exposure	Effects related to long-term exposure
Particulate matter	• Lung inflammatory reactions • Respiratory symptoms • Adverse effects on the cardiovascular system • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Increase in lower respiratory symptoms • Reduction in lung function in children • Increase in chronic obstructive pulmonary disease • Reduction in lung function in adults • Reduction in life expectancy, owing mainly to cardiopulmonary mortality and probably to lung cancer
Ozone	• Adverse effects on pulmonary function • Lung inflammatory reactions • Adverse effects on respiratory symptoms • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Reduction in lung function development
Nitrogen dioxide[a]	• Effects on pulmonary function, particularly in asthmatics • Increase in airway allergic inflammatory reactions • Increase in hospital admissions • Increase in mortality	• Reduction in lung function • Increased probability of respiratory symptoms

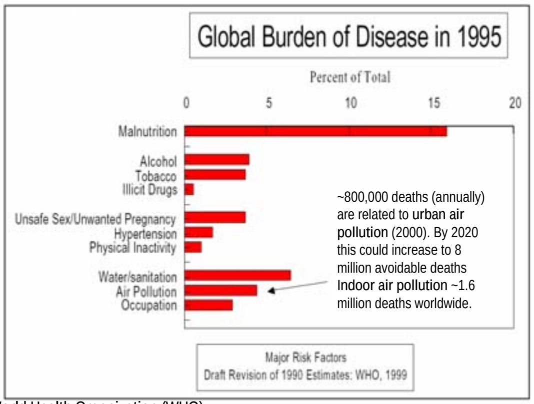
[a] In ambient air, nitrogen dioxide serves as an indicator for a complex mixture of mainly traffic-related air pollution.

World Health Organization, Health aspects of air pollution, 2004.

Healthy vs. Smoker Lung

Non-smoker lung - from a 47 year old city-dweller. The black spots are caused by carbon particles from air pollution

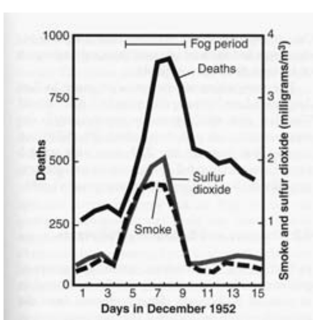
Blackened lung of a smoker. Whitish area is the developing area of lung cancer



World Health Organization (WHO)

http://www.arb.ca.gov/research/health/fs/pm-03fs.pdf

Killer Smog in London



Turco Figure 6.1

Human Impact

- Humans appear around 1 Million years ago
  hunters / gatherers

- Human settlements
  ~ 5000 - 10000 yrs ago

Early Human Impact (3000-1000 years ago)

- Agriculture
  cultivation of land
  burning of woods
  animal waste

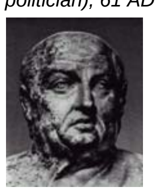
- Heating
  open wood fires indoors
  burning of coal

- Manufacturing:
  metals: copper, bronze, iron, etc.
  leather tanning

Early Human Impact

"As soon as I had gotten out of the heavy air of Rome and from
the stink of smoky chimneys thereof, which, being stirred, poured
forth whatever pestilential vapors and soot they had enclosed in
them, I felt an alteration of my disposition"

Seneca (Roman philosopher, dramatist, and politician), 61 AD

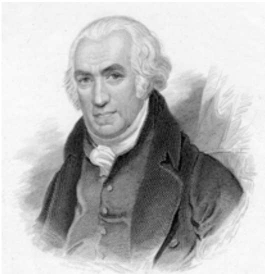


But:
world population small
~300 million people

individuals did not use as much energy

Industrialization

1784 Watt invents the steam engine fired by coal



Used to pump water out of mines; Energy for mills (paper, iron, flour, cotton, steel), distilleries, locomotives…

→ Hundred-fold global increase in coal combustion between 1800 and 1900.

James Watt (1736-1819)

Edgar Fahs Smith Collection, University of Pennsylvania Library

Examples

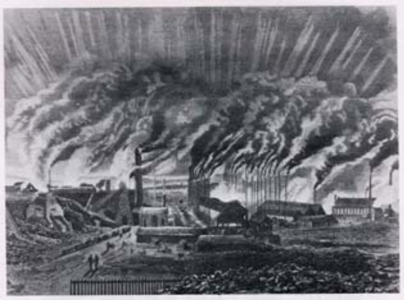


Fig. 1-4. Engraving (1876) of a metal foundry refining department in the industrial Saar region of West Germany. Source: The Bettmann Archive, Inc.

1876 AD

Coal combustion in U.S. ~ 1900s…

Reading, Pennsylvania (c. 1909)

Youngstown, Ohio (c. 1910)

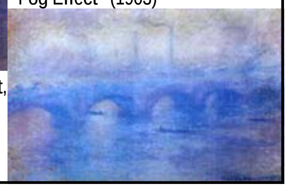
Gary, Indiana (c. 1912)

…for steel manufacturing, iron manufacturing, railway transportation

London Smog, 1900s

Claude Monet: “Houses of Parliament, Effects of Sunlight in the Fog” (1904)

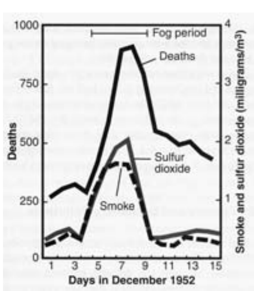
Claude Monet: “Waterloo Bridge, Fog Effect” (1903)



…London, 1900s

James Tissot: “The Thames” (1876)

London Smog of 1952



Turco Figure 6.1

BBC News
http://news.bbc.co.uk/1/hi/england/2543875.stm

Fog + smoke from coal burning
Worst single pollution episode in the UK. December 5-8 1952: 4,000 people died, another 8,000 died in the weeks-months that followed

Noontime, Donora, Pennsylvania, October 29, 1948

Pollution from steel mills and zinc smelters
Deadly episode: Oct 26-31 1948 – 20 people died, 7,000 people with respiratory illness “killer smog”

Smog Bothers Pedestrians, Los Angeles (1950s)

Factories + cars

Hollywood Citizens News Collection, Los Angeles Public Library

Urban smog

EPA’s ozone report, 2003 (http://www.epa.gov/airtrends/ozone.html)

Build-up of gases+particles in cities
Causes: Combustion products (cars, smokestacks…)+industry
Effects: Human+animal health; vegetation; structures
Scale: 10s-100s of kilometers
Time: 1850s-present

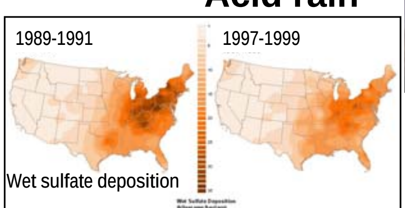
Urban smog around the world today

Acid rain

Sandstone figure, Westphalia, Germany

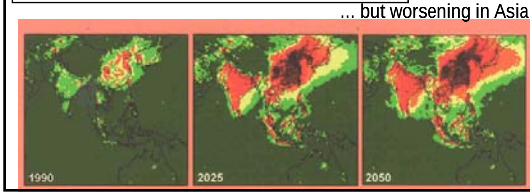
Acidification of rain
Causes: human-produced acids from combustion sources
Effects: Acidification of soils, forests, lakes (fish), structures
Scale: meters-1000s of kilometers
Time: 1850s-present

Acid rain



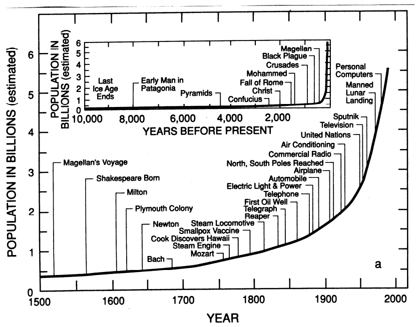
Getting better in the U.S.

... but worsening in Asia



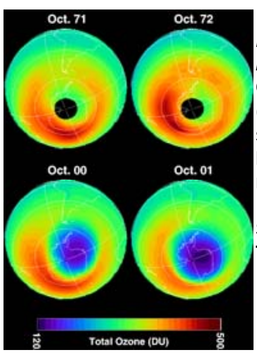
Growth of World Population

300 million 0 AD
1 billion in 1800
2 billion in 1927
3 billion in 1960
4 billion in 1974
5 billion in 1987
6 billion in 1999
9 billion 2050?



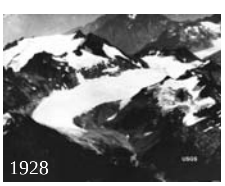
Agriculture, industry, and technology support population growth

Stratospheric ozone depletion



Human-induced destruction of ozone layer in stratosphere
Causes: Man-made chemicals (CFCs) used as refrigerants, solvents, sprays…
Effects: Increase in ultraviolet radiation reaching the ground →human+animal health
Scale: Global
Time: 1970s-present

Global Warming

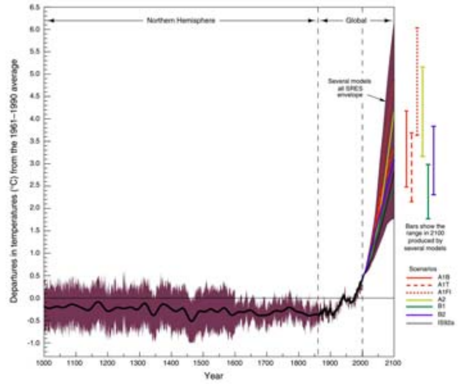


Retreat of the South Cascade glacier in the 20th century

Global climate change (temperature, rainfall, sea level rise…)
Causes: Greenhouse emissions gases (combustion, deforestation, agriculture)
Effects: Human health (malaria); animal/plant biodiversity; $$ cost (sea-level rise)
Scale: Global
Time: 1850s-present

Past and future surface temperature

1000 to 1861, N.Hemisphere, proxy data; 1861 to 2000 Global, instrumental; 2000 to 2100, SRES projections

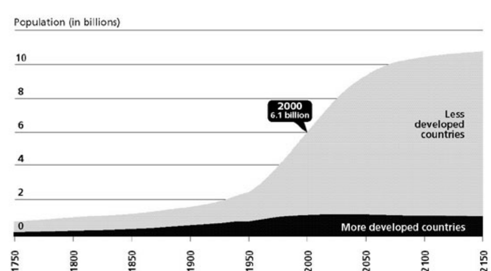


The Future

- Developed Countries:
  - high living standard
    - → high per-capita resource consumption
    - → more pollution per person
  - small population (~ 1 billion)
- Less developed Countries:
  - low living standard
    - → low per-capita resource consumption
    - → less pollution per person
  - large population (~ 5 billion)

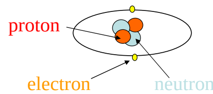
What is going to happen when/if poorer countries reach our lifestyle?

Future population



Source: United Nations, *World Population Prospects, The 1998 Revision* (New York: UN, 1998); and estimates by the Population Reference Bureau.

What is an atom?

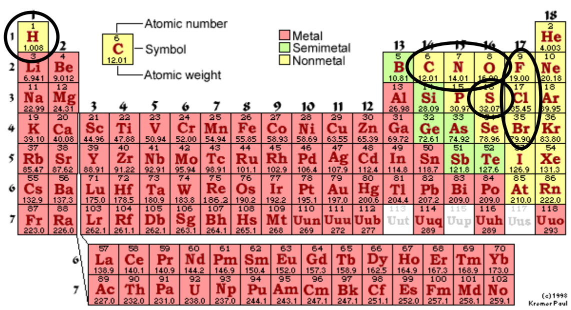


The kind of atom is determined by the number of protons and neutrons.

Nomenclature:

symbol	protons	neutrons	name
H	1	0	hydrogen
He	2	2	helium
N	7	7	nitrogen
C	6	6	carbon
O	8	8	oxygen

Periodic table of elements



Atomic number = # of protons

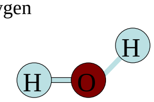
What is a molecule?

Two or more atoms that are bound together forming one unit.

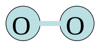
Nomenclature: hydrogen oxygen

water H_2O

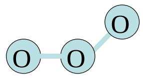
number of H atoms in molecule



Other Examples



Oxygen molecule: O_2



Ozone molecule: O_3

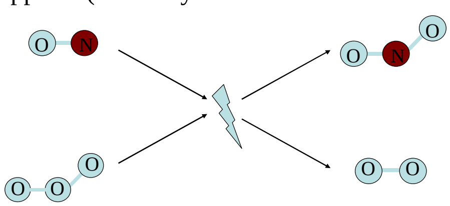
Carbon dioxide molecule: CO_2

Chemical Reactions

$O_3 + NO \rightarrow NO_2 + O_2$

we say:
O_3 (ozone) reacts with NO (nitric oxide) to form NO_2 (nitrogen dioxide) and O_2 (oxygen)

What happens: (not every collision leads to a reaction)



Nomenclature of Chemical Reactions

direction of reaction

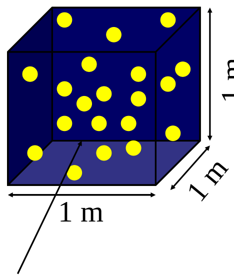
$O_3 + NO \rightarrow NO_2 + O_2$

reactants **products**

4 O atoms + 1 N atom = 4 O atoms and 1 N atom

Rules:
- the number of specific atoms, for example O, N, etc. are always the same on both sides.
- in air reaction only occur with 2 reactants
- whether a reaction occurs depends on many things, that we will not discuss in this class

Concentration



20 Tennis Balls
in the cube

$$C = \frac{\text{Amount of substance}}{\text{Volume}}$$

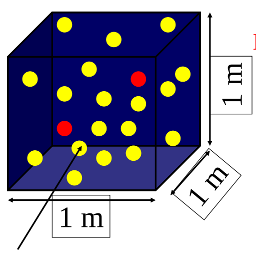
$$\text{Volume} = 1m \times 1m \times 1m = 1m^3$$

$$C = \frac{20\text{ balls}}{1\text{m}^3} = 20\frac{\text{balls}}{\text{m}^3}$$

Gas: molecules in Volume

$\Rightarrow$ unit: $\frac{\text{molec.}}{\text{cm}^3}$

Mixing Ratio (M.R.)



20 tennis balls
in the cube
2 of those red balls

$$\text{M.R.} = \frac{\text{Amount of one substance}}{\text{Amount of all substances}}$$

$$\text{M.R.} = \frac{2\text{ red balls}}{20\text{ balls}} = 0.1$$

no unit

Mixing Ratios

name	symbol	ratio	
One percent	1%	10^{-2}	one out of each 100
One part per million	1ppm	10^{-6}	one out of each million
One part per billion	1ppb	10^{-9}	one out of each billion
One part per trillion	1ppt	10^{-12}	one out of each trillion

Volume / Number

$$\text{M.R.} = \frac{\text{Amount of one substance}}{\text{Amount of all substances}}$$

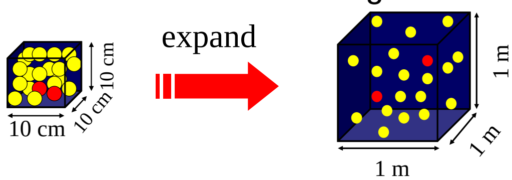
⇨ ppmv
ppbv

Mass

$$\text{M.R.} = \frac{\text{Mass of one substance}}{\text{Mass of all substances}}$$

⇨ ppmm
ppbm

Concentration vs. Mixing Ratio



$$C = \frac{20\ \text{balls}}{0.001\text{m}^3} = 20000\frac{\text{balls}}{\text{m}^3} \qquad C = \frac{20\ \text{balls}}{1\text{m}^3} = 20\frac{\text{balls}}{\text{m}^3}$$

$$\text{M.R.} = \frac{2\ \text{red balls} / 0.001\text{m}^3}{20\ \text{balls} / 0.001\text{m}^3} = 0.1 \qquad \text{M.R.} = \frac{2\ \text{red balls} / 1\text{m}^3}{20\ \text{balls} / 1\text{m}^3} = 0.1$$

Concentration changes, M.R. not!

How can we quantify the amount of a pollutant that comes out of a smoke stack?

How do we quantify the amount of pollutant a person breaths in?

Question

One car emits 10^{12} molecules of carbon monoxide (CO) in 1 hour, another car emits 10^{12} molecules CO in 30 minutes.

Which car is the worse polluter?

A third car emits 1013 molecules per day.

Is it better or worse than the other two?