Chapter 1

The Air We Breathe

What is in the air that we breathe?

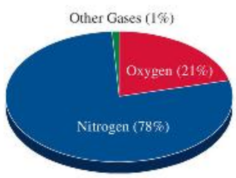
Can air be dangerous to our health?

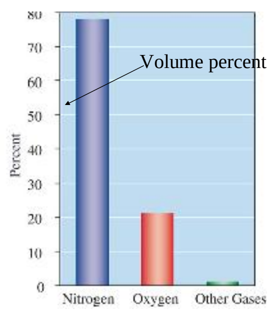
Issues of interest for the sustainability of the planet:

Air quality
Water quality
Food and nutrition
Public Health
Energy
..

The Composition of Our Air

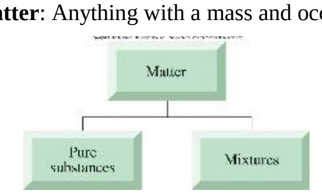
It's a mixture – a physical combination of two or more substances present in variable amounts.





Air is a mixture of Nitrogen, Oxygen, Argon, Carbon Dioxide,…

Matter: Anything with a mass and occupy space.



Substances with constant composition. e.g. gold (all elements), sugar, distilled water.

Mixture – a physical combination of two or more substances present in variable amounts. e.g cup of coffee, pop, dirt, mist, air.

What's in a Breath?

Typical Composition of Inhaled ("Clean") and Exhaled Air

Substance	Inhaled air (%)	Exhaled air (%)
Nitrogen	78.0	78.0
Oxygen	21.0 →	16.0
Argon	0.9	0.9
Carbon dioxide	0.0390 →	4.0
Water vapor	variable	variable

Atmosphere is 21% oxygen = 21 L per 100 L of air

21% means 21 parts per hundred parts

means 210 parts per thousand parts

means 2,100 parts per ten thousand parts

means 21,000 parts per hundred thousand parts

means 210,000 parts per million parts

The difference between pph (%) and ppm is a factor of 10,000

Scientific Notation: A review

$11000.0 = 1.10000 \times 10^{4}$

$0.00021 = 2.1 \times 10^{-4}$

$0.001021 = 1.021 \times 10^{-3}$

$1730.0 = 1.7300 \times 10^{3}$

Note: same number of significant figures on both sides of each example.

$6.022 \times 10^{-23} = 0.000,000,000,000,000,000,000,06022$

$602,200,000,000,000,000,000,000 = 6.022 \times 10^{23}$

Concentration Terms

Parts per hundred (percent)

Atmosphere is 21% oxygen = 21 L per 100 L of air

Parts per million (ppm)

Atmosphere is 21% oxygen = 210000 L per 1000000 L of air

$= 2.1\times10^{5}$ L per 1.0×10^{6} L of air

Parts per billion (ppb)

Atmosphere is 21% oxygen = 210000000 L per 1000000000 L of air

$= 2.1\times10^{8}$ L per 1.0×10^{9} L of air

Oxygen:

Essential to sustain life.

Key function: Inhaled oxygen is absorbed by blood; dissolved oxygen reacts with food (present in the body as sugars) to produce energy and heat - metabolism.

Waste products of metabolism of oxygen – carbon dioxide and water.

Air Pollutants

Generated from human activities and to a smaller extent by nature – air print; harmful for the health. The air pollution issue is acute in large cities.

- Carbon monoxide, CO
- Ozone, O_3
- Sulfur oxides (SO_3, SO_2) and nitrogen oxides (NO, NO_2)
- Particulate matter, PM

- Carbon monoxide, CO (interferes oxygen carrying capacity of blood, nausea → unconsciousness → death; indoor CO more dangerous because of accumulation: *autos, charcoal grills, stoves etc*.)
- Ozone, O_3 ground level (extremely reactive, inhalation damages lung tissues, retinal damage, cataracts, affects plants, marine life: *electric motors, photocopiers, welding*)
- Sulfur oxides and nitrogen oxides (smog, dissolves in moisture to form acid in lung thereby damaging it: *coal burning plants/stoves*)
- Particulate matter, PM (affects lungs: tiny solid or liquid particles, classified by size (μm): PM_{10}, $PM_{2.5}$ – *truck and car engines, burning coal, fires, blowing dust*).

Air Pollutants: Risk Assessment

Risk Assessment – evaluating scientific data and making predictions in an organized manner about the probabilities of an occurrence of a risk.

Based on:

- **Toxicity** – intrinsic health hazard of a substance. (based on animal studies)
- **Exposure** – the amount of the substance encountered.

Risk Warnings: Reports the likelihood of being affected by pollutants based on risk assessment.

Concentration Terms

Parts per hundred (percent)

Atmosphere is 21% oxygen =
21 oxygen molecules per 100 molecules in air

Parts per million (ppm)

Midday ozone levels reach about 0.4 ppm =
0.4 ozone molecules per 1×10^6 molecules in air

Parts per billion (ppb)

Sulfur dioxide in the air should not exceed 30 ppb =
30 sulfur dioxide molecules per 1×10^9 molecules in air

Table 1.2 U.S. National Ambient Air Quality Standards

Pollutant	Standard (ppm)	Approximate Equivalent Concentration (μg/m³)
Carbon monoxide		
8-hr average ←	9	10,000
1-hr average ←	35	40,000
Nitrogen dioxide		
Annual average	0.053	100
Ozone		
8-hr average ← (75ppb)	0.075	147
1-hr average	0.12	235
*Particulates**		
PM_{10}, annual average	—	50
PM_{10}, 24-hr average	—	150
$PM_{2.5}$, annual average	—	15
$PM_{2.5}$, 24-hr average[1]	—	35
Sulfur dioxide		
Annual average	0.03	80
24-hr average	0.14	365
3-hr average	0.50	1,300

Exposure – calculation based on,

a. Concentration of substance in air
b. Length of time
c. Rate of breathing

Example: An air sample has CO at 5000μg/m³ (5×10^3 μg/m³). Is it harmful to breathe? Use Table 1.2.

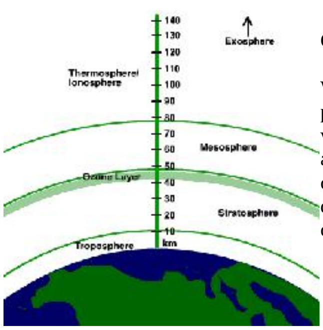
1-hr exposure: **40,000 «g/m³** i.e. 4×10^4 μg/m³ **(standard allowed)** greater than 5000 μg/m³ – **OK**.

8-hr exposure: **10,000 «g/m³** i.e. 1×10^4 μg/m³ (standard **allowed)** greater than 5000 μg/m³ – **OK**.

Quality of air changes form locality to locality.

Differences in the quality of air depends on;

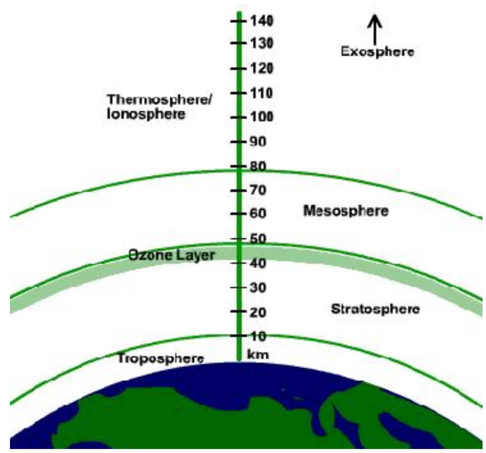
a. population of the location
b. activity of the habitants
c. activities in the neighboring regions
d. local weather patterns
e. geographical features of location



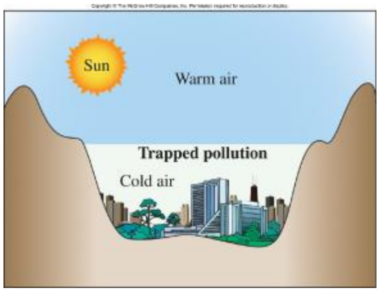
Geographically flat locality:

Warm air rises up carrying pollutants with it. Mixes with air in the upper atmosphere due to air currents in troposphere, diluting the concentrations of pollutants.

http://mistupid.com/science/atmosphere.htm



geographical features of location

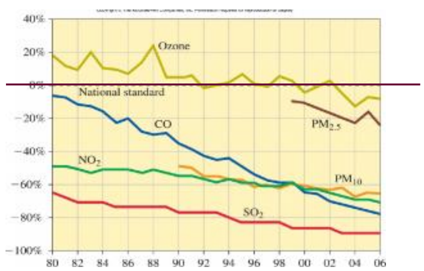


Inversion layer formation due to valley like geographical formation; cold air trapped, do not reach troposphere increasing accumulating the pollutants.

U.S. Clean Air Act (1970) *and* *Pollution Prevention Act (1990)* established air quality standards and authority to control hazardous substances.

Objective - Pollution prevention or reduction pollution *at the source of pollution*, whenever feasible.

Average concentrations of air pollutants at selected locations in the U.S., in comparison with national ambient air quality standards. *Continuous improvement.*



However no law is perfect!

Table 1.3 Air Quality Data for Selected U.S. Metropolitan Areas

Metropolitan Area	# of Unhealthy Days/Year* O_3	$PM_{2.5}$
Boston	10	5
Chicago	11	10
Cleveland	17	9
Houston	35	2
Los Angeles	62	38
Pittsburgh	14	42
Phoenix	10	2
Sacramento	28	10
Seattle	1	4
Washington, DC	19	8

EPA's Air Quality Index

Based on the highest pollutant measured.

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*...air quality conditions are:*	*...as symbolized by this color:*
0–50	Good	Green
51–100	Moderate	Yellow
101–150	Unhealthy for sensitive groups	Orange
151 200	Unhealthy	Red
201 300	Very unhealthy	Purple
301 500	Hazardous	Maroon

AQI

Scale 1-500

Any pollutant assigned a value of 100 for it's standard concentration.

CO, 35ppm =100

SO_2, 0.50ppm = 100

Pollutant	Standard (ppm)
Carbon monoxide	
8-hr average	9
1-hr average	35
Nitrogen dioxide	
Annual average	0.053
Ozone	
8-hr average	0.075
1-hr average	0.12
*Particulates**	
PM_{10}, annual average	—
PM_{10}, 24-hr average	—
$PM_{2.5}$, annual average	—
$PM_{2.5}$, 24-hr average†	—
Sulfur dioxide	
Annual average	0.03
24-hr average	0.14
3-hr average	0.50

Figure 1.9 Air Quality Index values for Phoenix

FORECAST DATE AIR POLLUTANT	YESTERDAY WED 05/13/2009 Highest AQI Reading/SITE	TODAY THU 05/14/2009	TOMORROW FRI 05/15/2009	EXTENDED SAT 05/16/2009
O_3	61 CAVE CREEK & FOUNTAIN HILLS	80 MODERATE	97 MODERATE	104 UNHEALTHY FOR SENSITIVE GROUPS
CO	07 GREENWOOD	09 GOOD	11 GOOD	09 GOOD
PM_{10}	53 WEST FORTY THIRD	55 MODERATE	61 MODERATE	48 GOOD
$PM_{2.5}$	45 PHOENIX SUPERSITE	46 GOOD	49 GOOD	45 GOOD

Variations reflect those in the local weather patterns. Regional events such as forest fires and volcanic eruptions can influence air quality.

1.4

Air Quality in Hawai'i Volcanoes National Park:

Warning sign along crater trail

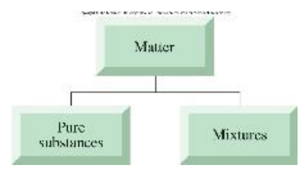
Green Chemistry started because of the need to reduce and/or eliminate the hazardous chemicals with an impetus from the pollution prevention legislation.

Goal of Green Chemistry - Benign by design.

Green chemical methods of manufacture has indeed accomplished this feat and is continuing.

ACS Green Chemistry Institute

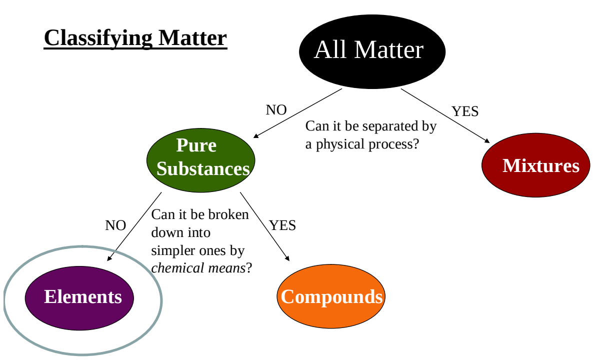
Anything with a mass and occupy space.



Substances with constant composition. e.g. gold (all elements), sugar, silica, distilled water.

Mixture – a physical combination of two or more substances present in variable amounts. e.g cup of coffee, pop, dirt, mist, air.

Classifying Matter



Elements:

Basic/simplest materials out of which all matter is derived from. All matter is made up of elements.

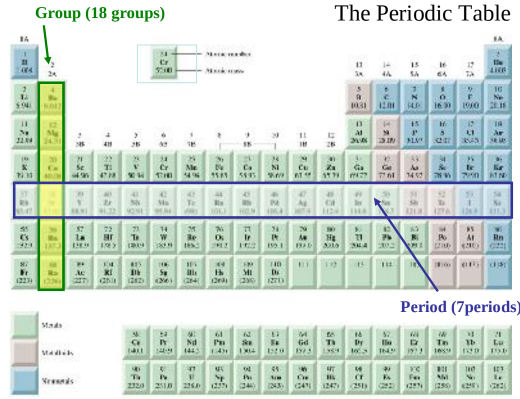
There are a little more than 110 different elements known as of now. Each element has it's own chemical and physical properties.

Every element has a given unique *name and a symbol*, e.g. Helium He; Nitrogen N.

Systematic arrangement of these elements based on a fundamental property, namely, the atomic numbers of the elements leads to a table;

Periodic Table of the elements.

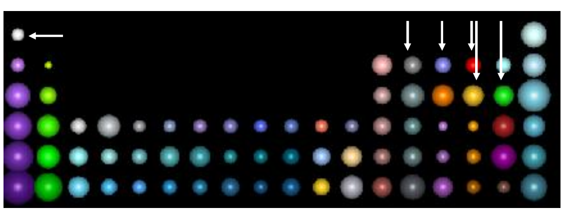
The Periodic Table



Atom:

Smallest particle of an element that retains the chemical properties of that element.

We use a sphere to model an atom. Atoms of each element is assigned a color.



There are about 110 **elements**, 90 naturally occurring.

They combine (to form compounds) in millions of ways

> 20 million compounds identified.

Compounds:

Most substances contains atoms of different elements in combined (***bonded***) form ⟶ compound.

i.e. compounds are made up by the combination of elements. Compounds are NOT a mixture of elements.

Properties of compounds are distinctly different from the properties of the elements from which they are formed.

sodium + chlorine → salt
hydrogen + oxygen → water

Classifying Matter

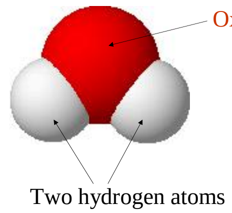
Classify each of these as an element, a compound, or a mixture:

carbon dioxide	**compound**
nickel	**element**
cocaine	**compound**
water	**compound**
fluorine	**element**
table salt	**compound**
soap	**mixture**
sea water	**mixture**

Molecule:

Smallest particle of a ‘substance (compound)’ that exhibits same chemical properties as a bulk sample of the compound.

A space-filling model for a water molecule, H_2O.

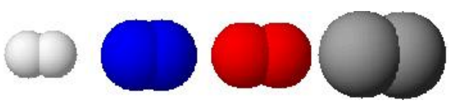


A molecule has a fixed number of atoms held together by chemical bonds in a certain spatial arrangement.

The chemical formula symbolically represents the type and number of each element present.

1.7

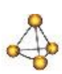
Many nonmetals occur as diatomic (made up of two atoms) molecules.



H_2 N_2 O_2 Cl_2

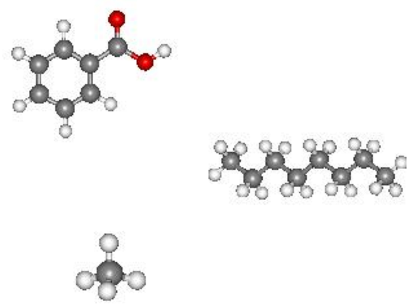
Few other nonmetals occur as polyatomic made up of more than two atoms) molecules.

S_8, P_4.



Group 8A or 18 elements; inert gases or noble gases are mono-atomic.

1.7



Compounds:

A pure substance/compound has the same composition and properties regardless of its source. **

The fact that elemental composition (chemical make up) of a compound is always the same;

$\Rightarrow$ *Law of constant composition.*

Naming Binary (two element) Compounds

1. Prefixes - designates the number of each type of element:

number of atoms	prefix
1	mono
2	di
3	tri
4	tetra
5	penta
6	hexa
7	hepta
8	octa
9	nona
10	deca

1.8

Binary - two element molecules.

format:
prefix(>1)(more +ve atom) prefix (less +ve atom)ide

Naming Binary Compounds of Nonmetals

N_2O = dinitrogen monoxide (laughing gas)

P_2O_5=diphosphorus pentoxide

Notice the dropped “a” from “penta” – when both the prefix and suffix (in this case “oxide”) end and start, respectively, in a vowel, the vowel of the prefix is typically dropped; pentoxide rather than pentaoxide.

1.8

Naming Binary Compounds of Nonmetals

2. Prefixes are used to designate the number of each type of element:

N_2O = dinitrogen monoxide (laughing gas)

P_2O_5=diphosphorus pentoxide

1.8

Nomenclature of Molecules:

Binary - two element

format:
prefix(>1)(more +ve atom) prefix (less +ve atom)ide

Cl_2O

Cl_2O *di*chlorine *mono*xide

NF_3
N_2O_4
P_4S_{10}

NF_3 nitrogen trifluoride
N_2O_4 dinitrogen tetroxide
P_4S_{10} tetraphophorous decasulfide

Chemical Reactions:

Reactions result in formation of substances different from the starting (reactants) substance.

Reactions change the partnership(s) of atoms.

However the total number of atoms of an element before the reaction and after the reaction are the sam;

Ĝ **Law of Conservation of Mass**

Chemical reactions are characterized by the rearrangement of atoms when **reactants** are transformed into **products.**

$$\underbrace{C + O_2}_{\text{reactants}} \longrightarrow \underbrace{CO}_{\text{product}}$$

This is an example of a **combustion reaction**

The number of atoms on each side of the arrow must be equal (**Law of Conservation of Mass**).

$$2\,C + O_2 \longrightarrow 2\,CO \quad \text{(balanced)}$$

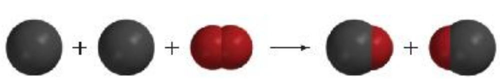
2 carbon atoms — two carbon atoms
2 oxygen atoms — two oxygen atoms

Chemical Reactions:

Reactions change the partnership(s) of atoms.

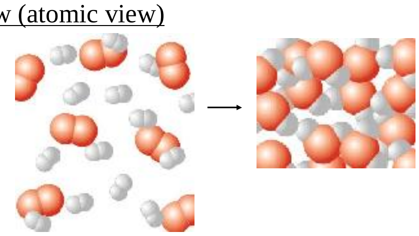
The total number of atoms of an element before the reaction and after the reaction are the same.

$$2\,C \quad + \quad O_2 \longrightarrow 2\,CO$$



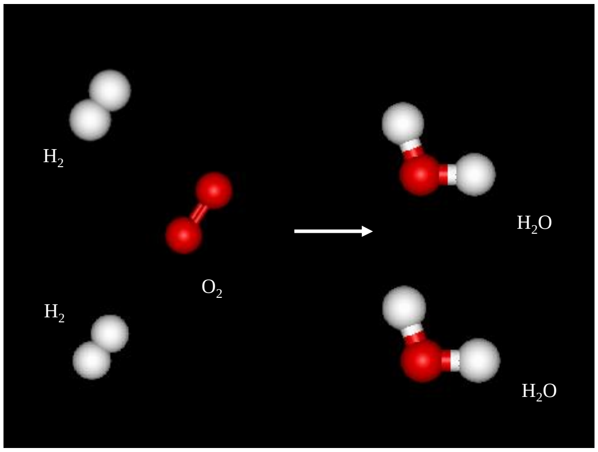
Types of Chemical Reactions – Animation - Youtube

Nanoview (atomic view)



Symbolic Representation:

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$$



Balancing equations:

$$C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$$

1. if an element is present in just one compound on each side, balance it *first*
2. balance anything that exists as a free element *last*
3. balance polyatomic ions as a unit
4. check when done – same number of atoms, and same total charge (if any) on both sides

$$C_3H_8 + 5\,O_2 \longrightarrow 3\,CO_2 + 4\,H_2O$$

3 C atoms	3 C atoms
8 H atoms	8 H atoms
10 O atoms	10 O atoms

1.9

Air Pollutants:

Sources of air pollution (non natural): motor vehicles (burning gas), coal fired electricity generating plants.

Pollutants:
CO
VOCs (volatile organic compounds)
NO, NO_2 (NO_x)
PM
O_3 (secondary pollutant))
and *SO_2, SO_3*

Burning (Combustion) and Oxygen:

Burning involves a fuel and an oxidant. *The oxidant almost always is oxygen from air.*

Fuels are compounds rich in C and H.

Most fuels are hydrocarbons – compounds containing mainly C and H (e.g. natural gas=methane, CH_4; *Gasoline has a **mix** of volatile hydrocarbons, additives and lot of octane, C_8H_{18};* kerosene has a mix of hydrocarbons; wood).

Burning Hydrocarbons:

Burning them in air (*complete combustion*) converts all C to CO_2 and H to H_2O by reacting with O_2 in air.

Methane $CH_4 + O_2 \rightarrow CO_2 + H_2O$

Octane $C_8H_{18} + O_2 \rightarrow CO_2 + H_2O$

Problem: incomplete combustion, CO

Gasoline: $C_8H_{18} + O_2 \rightarrow CO + H_2O$

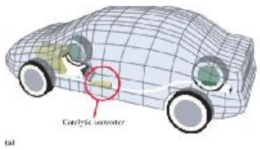
Pollutant (major)
– auto emission

Soot (particles) is also formed due to incomplete combustion.

Catalytic converters are used to catalyze the conversion of CO to CO_2.

Catalysts are substances that would accelerate a reaction without itself being used up.

$$CO + O_2 \rightarrow CO_2$$



1.11

The catalytic converters also reduce the amount of Volatile Organic Compounds (VOCs) in exhaust by helping the complete burning of the un-burnt hydrocarbons etc. to CO_2 and water.

Gasoline has to be reformulated to use catalytic converters.

Reasons for removing tetraethyl lead from the ***mix*** in gasoline is that the lead gunked up or poisoned the catalysts in the converters; and to reduce the amount of lead pollution in the air.

Direct Source of Nitrogen Oxides

$$N_2 + O_2 + \text{high temp} \rightarrow 2\ NO$$

(nitrogen oxide)

High temperatures in <u>auto engine or coal-fired power plant</u>

NO is very reactive:

$$2\ NO + O_2 \rightarrow 2\ NO_2$$

$$NO + O_3 \rightarrow 2\ NO_2$$

(nitrogen dioxide)

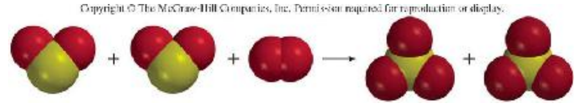
1.11

Direct Source of Sulfur Trioxide

(Coal) $S + O_2 \longrightarrow SO_2$

(1–3% sulfur)

$$2\ SO_2 + O_2 \longrightarrow 2\ SO_3$$



Good News: Since 1985 we have seen a 25% reduction in SO_2 emissions in the U.S.!!

1.11

Other reactions: in damp conditions.

$$NO + H_2O \rightarrow HNO_2$$

$$NO_2 + H_2O \rightarrow HNO_3$$

⇒ Acid (rain)
Condensation in lungs

$$SO_2 + H_2O \rightarrow H_2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Ashes (PM) from coal burning accelerates the condensation of water and therefore acid formation rate near coal burning plants

Volatile Organic Compounds (VOCs)

VOCs = Compounds that easily evaporate under normal temperatures. Sources: incompletely burnt gasoline, leaks and spills from manufacturing plants of organic materials, forests.
Responsible for the generation of ozone in the troposphere in an indirect manner via NO_2.

$$VOC + {}^{\bullet}OH \rightarrow A$$

$$A + O_2 \rightarrow A'$$

$$A' + NO \rightarrow A'' + NO_2$$

Hydroxyl radical, $^{\bullet}OH$, exist in air in very small amounts.

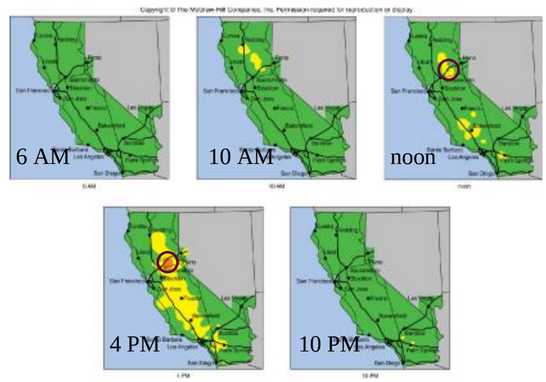
Ozone (secondary pollutant: not produced directly but as the product of the interaction of two or more pollutants):

Highly undesirable in the troposphere. Damages lungs, crops and leaves. **Beneficial in stratosphere to prevent UV radiation from reaching the earths surface.**

Formation: $NO_2 \xrightarrow{\text{sunlight}} NO + O$
$O + O_2 \rightarrow O_3$

Hydroxyl radical, $^{\bullet}OH$, exist in air in very small amounts and is very reactive.

Atomic O is very reactive too.



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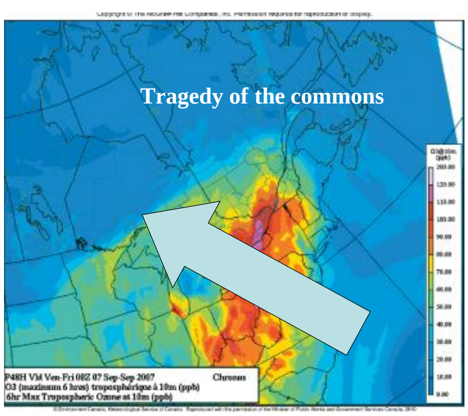

1.12

Tragedy of the commons

The **tragedy of the commons** is a dilemma arising from the situation in which multiple individuals, acting independently and rationally consulting their own self-interest, will ultimately deplete a shared limited resource, even when it is clear that it is not in anyone's long-term interest for this to happen.

Wikipedia description

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

Indoor Air Pollutants?

Do you think of harmful pollutants when you light your incense candle or want to begin painting a room in the house? Why do you think these are considered indoor air pollutants?

1.13

Reading assignment:

Particulate matter. p.46

Indoor air quality Section 1.13 p. 49

Some Calculations

Q: If one breath of air contains 2 ò 10^{22} molecules and atoms, and the acceptable ozone level is 0.12 ppm, how many molecules of O_3 are in each breath?

$0.12\text{ppm} = 10^6$ molecules and atoms contain 0.12 molecules of O_3

10^6 molecules and atoms $\Leftrightarrow$ 0.12 molecules of O_3

$$2\times10^{22}\text{ molecules and atoms} \Leftrightarrow 0.12 \text{ molecules of } O_3 \times \frac{2\times10^{22}}{10^6}$$

$$= 2\times10^{15} \text{ molecules of } O_3$$

$$\boxed{= 2 \times 10^{15}\ O_3 \text{ molecules in a breath}}$$

How many oxygen *atoms* *<u>from ozone</u>* are in each breath?

$$2 \times10^{15}\ O_3\ \text{molecules} \left(\frac{3\ \text{O atoms}}{1\ O_3\ \text{molecules}}\right) = 6 \times 10^{15}\ \text{O atoms}$$

1.14

Q: If one breath of air contains 2 ò 10^{22} molecules and atoms, and the acceptable CO level is 9 ppm, how many molecules of CO are in each breath?

$9\text{ppm} = 10^6$ molecules and atoms in air contain 9 molecules of CO

10^6 molecules and atoms $\Leftrightarrow$ 9 molecules of CO_3

$$2\times10^{22}\text{ molecules and atoms} \Leftrightarrow 9 \text{ molecules of CO} \times \frac{2\times10^{22}}{10^6}$$

$$= 1.8\times10^{17} \text{ molecules of } O_3$$