Chemical Transformations (air pollution)

Chemical Changes Described by Chemical Equations

Chemical equation: Reactant(s) ⟶ Product(s)

Table 1.8 Characteristics of Chemical Equations

Always Conserved

Identity of atoms in reactants = Identity of atoms in products

Number of atoms in reactants = Number of atoms in products

Mass of all reactants = Mass of all products

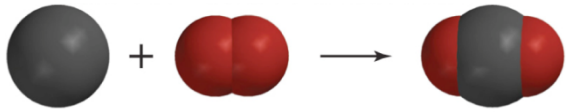
May Change

Number of molecules in reactants vs. Number of molecules in products

Physical states (*s*, *l*, or *g*) of reactants vs. physical states of products

Carbon reacts with oxygen to form carbon dioxide (complete combustion):

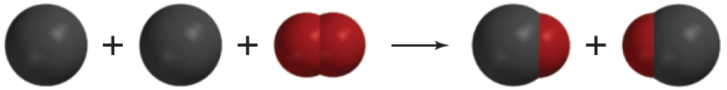
$$C + O_2 \longrightarrow CO_2$$



balanced equation

subscripts: # of atoms in a molecule
in front = # of molecules in eqn.

When not enough O_2 is present, carbon monoxide is produced, and CO poisoning can occur:

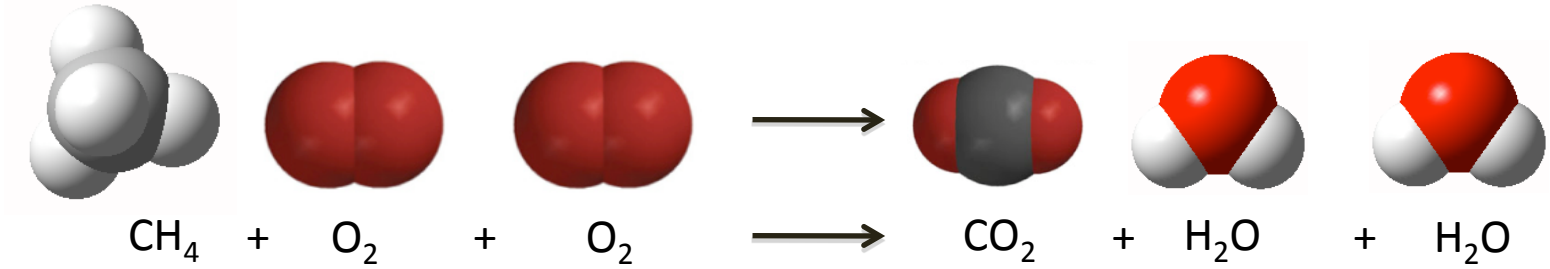


$$C + O_2 \longrightarrow CO \quad \Rightarrow \quad 2C + O_2 \longrightarrow 2CO$$

Burning to Balance Equations

Natural gas combustion: methane plus oxygen produces carbon dioxide plus water

$CH_4 + O_2 \rightarrow CO_2 + H_2O$ *not balanced: 4 H's on left and 2 H's on right, 2O's on left & 3 on right*



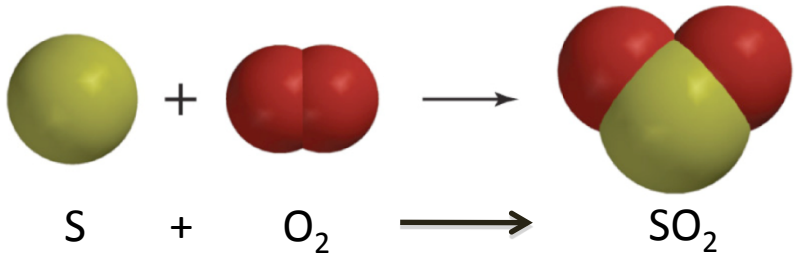
$CH_4 + O_2 + O_2 \rightarrow CO_2 + H_2O + H_2O$

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

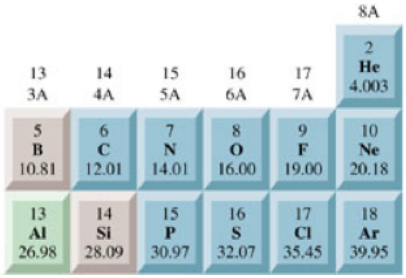
in front indicates # molecules
Subscripts: # of atoms in a molecule

2x2=4

Small amount of sulfur present in coal
(it's removed during petroleum refining)

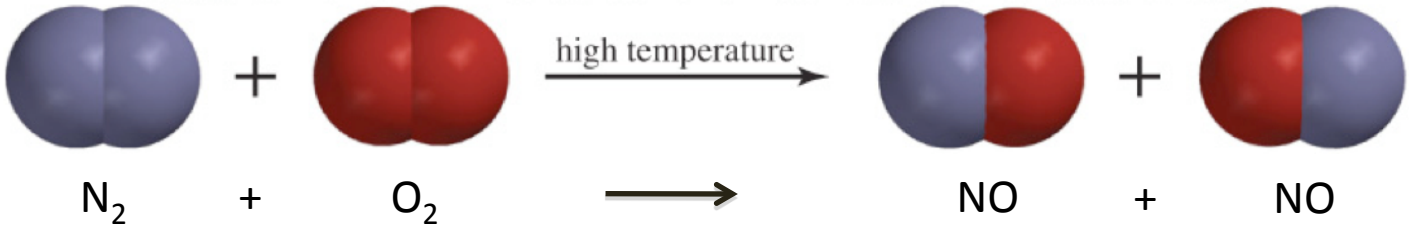


$S + O_2 \rightarrow SO_2$



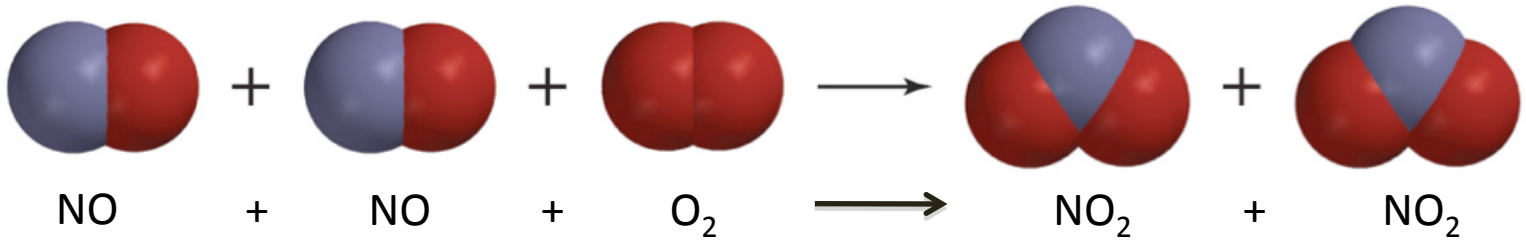
Burning Nitrogen

Nitrogen (N_2) not very reactive but is 78% of air and does react at high temperatures:



$N_2 + O_2 \rightarrow 2NO$

Nitrogen monoxide (nitric oxide), a primary pollutant, is reactive but needs to be present in a high concentration to react further with air to form NO_2, a secondary pollutant:

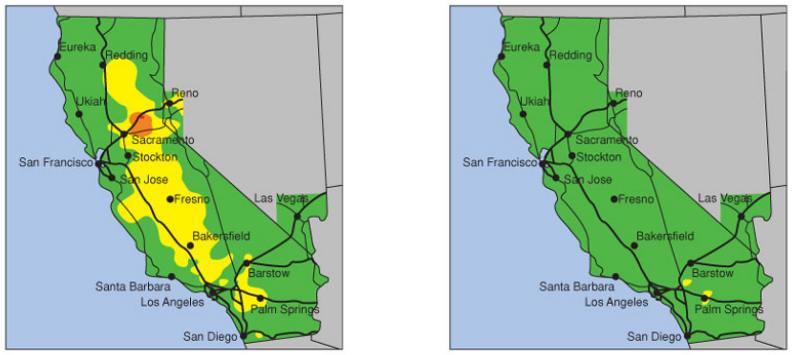


$2NO + O_2 \rightarrow 2NO_2$

Ozone as a Secondary Air Pollutant

Ozone level maps for a summer day in California, July 2006

6 AM | 10 AM | Noon



4 PM | 10 PM

green yellow orange

increasing O_3 concentration

$$VOC + \bullet OH \rightarrow A$$
$$A + O_2 \rightarrow A'$$
$$A' + NO \rightarrow A'' + NO_2$$

A, A', and A" produced from oxidation of VOC

$$NO_2 \xrightarrow{\text{sunlight}} NO + O$$

$$O + O_2 \longrightarrow O_3$$

VOC: volatile organic compounds

Sources of Important Air Pollutants

Major Direct Sources:

1. *Hydrocarbon (coal & petroleum) combustion: SO_2 & inorganic ash from coal*

Approximate coal formula: $C_{135}H_{96}O_9NS$

$S + O_2 \rightarrow SO_2$

$2SO_2 + O_2 \rightarrow 2SO_3$ slow in air (gas) but faster on particles (ash)

$SO_3 + H_2O \rightarrow H_2SO_4$ slow in air (gas) but faster on particles (ash) & high humidity

note: combinations of solid and liquid that remain suspended in the atmosphere are **aerosols**

2. *NO, CO, particulates & VOC (volatile organic compounds) from burning gasoline*

$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$ (complete combustion, no problem here)

$2C_8H_{18} + 17O_2 \rightarrow 16CO + 18H_2O$

$< 17O_2$ leads to unburned or partially burned organic compounds (VOCs)

$N_2 + O_2 \rightarrow 2NO$

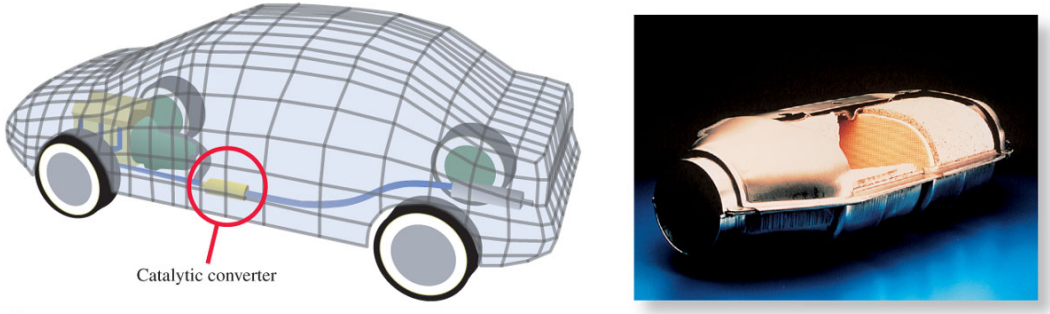
$2NO + O_2 \rightarrow 2NO_2$ slow in air but accelerated by VOC & $OH^{\bullet}$

Driving Away Air Pollution

What have we/are we/can we do to reduce air pollution?

Green chemistry: designing chemical products & processes that reduce or eliminate the use or generation of hazardous substances

- Drive less
- Burn less (greater mpg)
- Properly tuned engine
- Catalytic converters (burns VOC, converts CO to CO_2, & helps with NO)
  - catalytic converters poisoned by lead & other heavy metals
  - tetraethyl lead (TEL, $Pb(C_2H_5)_4$) used to be employed to eliminate “knocking”
  - because of impact on catalytic converters & toxic nature of Pb compounds we now use *UNLEADED* gas
- Particulate filters (esp. for diesel engines)



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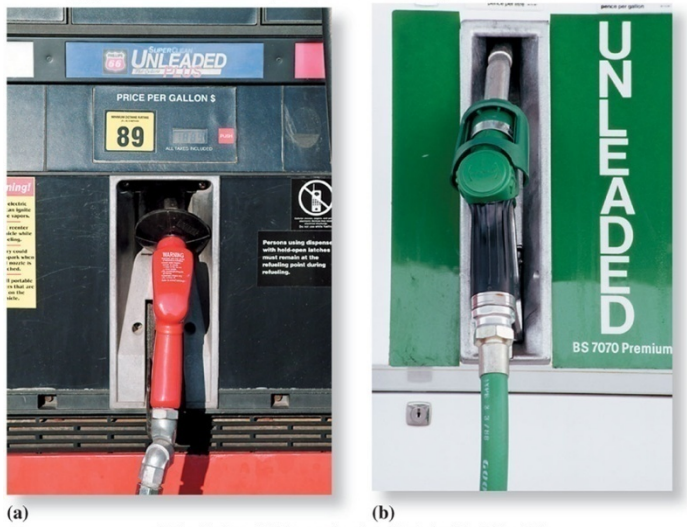

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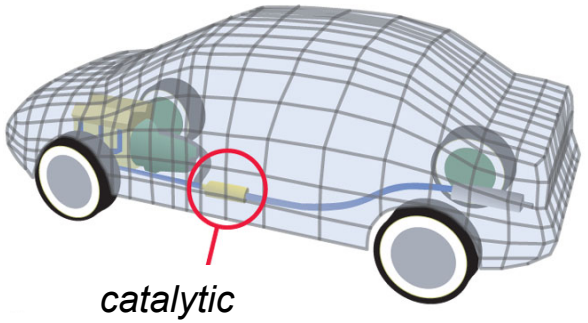
Driving Away Air Pollution

What have we / are we / can we do to reduce air pollution?

- Conservation
  - drive less
  - burn less (increase fuel efficiency)
- Technological fixes
  - properly tuned engines (gas:air ratio is important for complete combustion)
  - particulate filters (especially for diesel engines)
  - catalytic converters: burns VOC, converts CO to CO_2, & helps remove NO
- Legislation
  - fuel efficiency standards
  - measuring and regulating pollutant concentrations
  - removing lead compounds (tetraethyl lead, TEL, used to be used as an anti-knock agent, but found to be highly toxic)

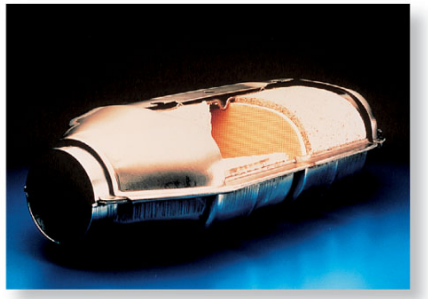


catalytic converter

(b)

More About Catalytic Converters

- example of green chemistry
- precious metals like Rh, Pt immobilized on a porous silica surface ($$$)
- they **catalyze** the reaction of pollutants to produce more benign products
  - **oxidizes** (for our purposes, burns) VOCs, CO to CO_2 and H_2O
  - **reduces** NO to N_2 and O_2
- few metals can oxidize and reduce under the same conditions; the air:gas ratio is important
  - too much gas ➔ reduction preferred
  - too much air ➔ oxidation preferred
- catalytic converters are poisoned by sulfur heavy metals like Pb
  - force use of unleaded gasoline and desulfurization of gasoline

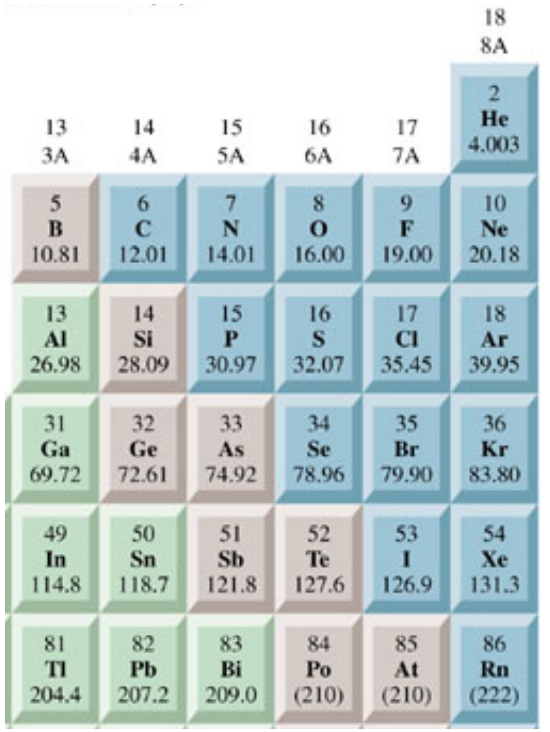


8	9	10	11	12	13	14	15	16
	8B		1B	2B	Al 26.98	Si 28.09	P 30.97	S 32.07
26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96
44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6
76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)

Green chemistry: designing chemical products & processes that reduce or eliminate the use or generation of hazardous substances

Indoor Air Quality

- Common pollutants
  - Radon (especially in the mountain west region)
  - asbestos
  - dust, dander
  - (cigarette) smoke
  - CO
- Balancing energy efficiency with air circulation
- New cook stove technologies



13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
					2 He 4.003
5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)

3×10^9 people use wood (or related) fires for cooking
1.5×10^6 people die from indoor air pollution annually
85% of those people are women and children

CSU-linked venture to improve combustion efficiency:
http://www.envirofit.org/