Energy Intro

How do we access chemical energy?

Carry out chemical transformations which change the types (and strengths of) chemical bonds

Why do combustion reactions give off energy?

X-O bonds tend to be stronger than X-X and O-O bonds

Order wood, Coal, Natural Gas (methane), gasoline (C_8H_{18}), and ethanol in terms of energy content (per gram) using Table 4.3

CH_4> gasoline>coal~ethanol>wood

Table 4.3 Energy Content of Fuels

Source	kJ/g
Hydrogen	140
Methane	56
Propane	51
Gasoline	48
Coal (hard)	31
Ethanol	30
Wood (oak)	14

Question

For bonds between the following pairs of atoms, in which **one** would you expect the 2nd atom of the pair to gain electrons?

a) C and N
b) O and Cl
c) Be and Na
d) Cl and S

Table 5.3 Electronegativity Values, Arranged by Group Number

1A	2A	3A	4A	5A	6A	7A	8A
H							He
2.1							—
Li	Be	B	C	N	O	F	Ne
1.0	1.5	2.0	2.5	3.0	3.5	4.0	—
Na	Mg	Al	Si	P	S	Cl	Ar
0.9	1.2	1.5	1.8	2.1	2.5	3.0	—

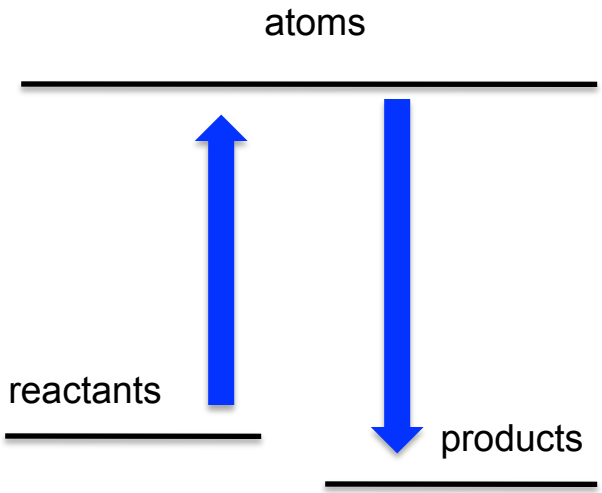
Bond Energy Calcs

Is the reaction of nitrogen with hydrogen to form ammonia exothermic?

$N_2 + 3H_2 \rightarrow 2NH_3$

If – exothermic
If + endothermic

+946 kJ/mol+3x436 kJ/mol-2x3x391 kJ/mol=-92 kJ/mol



Need to know bonding
(Dot diagrams/#bonds)

Table 4.2 Bond Energies (in kJ/mol)

	H	C	N	O	S	F	Cl	Br	I
Single Bonds									
H	436								
C	416	356							
N	391	285	160						
O	467	336	201	146					
S	347	272	—	—	226				
F	566	485	272	190	326	158			
Cl	431	327	193	205	255	255	242		
Br	366	285	—	234	213	—	217	193	
I	299	213	—	201	—	—	209	180	151
Multiple Bonds									
C=C	598			C=N	616		C=O	803 in CO_2	
C≡C	813			C≡N	866		C≡O	1073	
N=N	418			O=O	498				
N≡N	946								

Source: Data from Darrell D. Ebbing, *General Chemistry,* Fourth Edition, 1993 Houghton Mifflin Co. Data originally from *Inorganic Chemistry: Principles of Structure and Reactivity,* Third Edition, by James E. Huheey, 1983, Addison Wesley Longman.

Bond Energy calcs, cont.

Is the reaction of diimide with hydrogen to form ammonia exothermic?

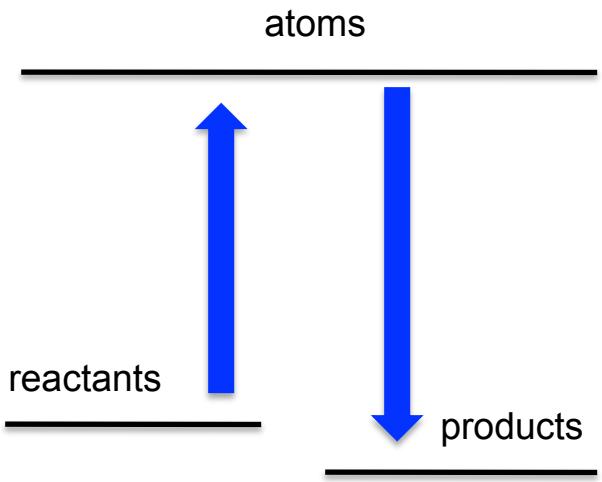
$N_2H_2 + 2H_2 \rightarrow 2NH_3$

+418 kJ/mol+2x391 kJ/mol+2x436 kJ/mol-2x3x391 kJ/mol=-274 kJ/mol

What about hydrazine?

$N_2H_4 + H_2 \rightarrow 2NH_3$

+160 kJ/mol+4x391 kJ/mol+436 kJ/mol
-2x3x391 kJ/mol=-622 kJ/mol



Need to know bonding
(Dot diagrams/#bonds)

Table 4.2 Bond Energies (in kJ/mol)

	H	C	N	O	S	F	Cl	Br	I
Single Bonds									
H	436								
C	416	356							
N	391	285	160						
O	467	336	201	146					
S	347	272	—	—	226				
F	566	485	272	190	326	158			
Cl	431	327	193	205	255	255	242		
Br	366	285	—	234	213	—	217	193	
I	299	213	—	201	—	—	209	180	151
Multiple Bonds									
C=C	598			C=N	616		C=O	803 in CO_2	
C≡C	813			C≡N	866		C≡O	1073	
N=N	418			O=O	498				
N≡N	946								

Source: Data from Darrell D. Ebbing, *General Chemistry,* Fourth Edition, 1993 Houghton Mifflin Co. Data originally from *Inorganic Chemistry: Principles of Structure and Reactivity,* Third Edition, by James E. Huheey, 1983, Addison Wesley Longman.

Energy content

Energy content of fuels

The text (p. 166) gives the equation for combusting glucose as giving off 2800 kJ, What is the energy content of glucose per gram?

$$2800\ \text{kJ} \times \frac{1\ \text{mole}}{180.18\ \text{g}} = 16\ \text{kJ/g}$$

6x12.01
+12x1.01
+6x16.00
=180.18 g/mol

Table 4.3 Energy Content of Fuels

Source	kJ/g
Hydrogen	140
Methane	56
Propane	51
Gasoline	48
Coal (hard)	31
Ethanol	30
Wood (oak)	14

Unit 2.2 Summary

- Balancing chemical reactions leads to insight on pollution
  - e.g. complete vs incomplete combustion
  - e.g. catalytic conversion of CO to CO_2

- atomic structure and periodicity
  - composition of atoms: protons, neutrons, electrons
  - groups have the same number of valence electrons and similar properties
  - atomic reactivity based on achieving the same number of valence electrons as the noble gas in that atom's group
- Lewis (dot) structures
  - atoms make (covalent) bonds to satisfy the octet rule (most of the time)

- mass and the mole
  - mole is a counting unit, just like dozen…only a lot bigger: Avogadro's # is 6.02×10^{23}
  - use balanced chemical equations and unit analysis to determine things like the amount of carbon put into the atmosphere

Air Pollution

What's in air?

N_2, O_2, Ar, CO_2, H_2O

What are the major pollutants that we talked about?

CO, NO_2, SO_2, O_3, PM_x, VOCs

Where do/did they come from?

Combustion of natural gas, petroleum & coal

What's matter?

Mixtures/pure substances/elements/compounds

What have we/are we/can we do?

1. Drive less
2. Burn less (greater mpg)
3. Properly tuned engine
4. Catalytic converters (burns VOC, converts CO to CO_2, & helps with NO)
5. Use less energy

Balanced Chemical Equations

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

Ethanol (C_2H_6O) reacts with oxygen to form carbon dioxide and water
Write the balanced chemical equation for this.

Atoms are made up of three elementary particles:

Table 2.1 Properties of Subatomic Particles

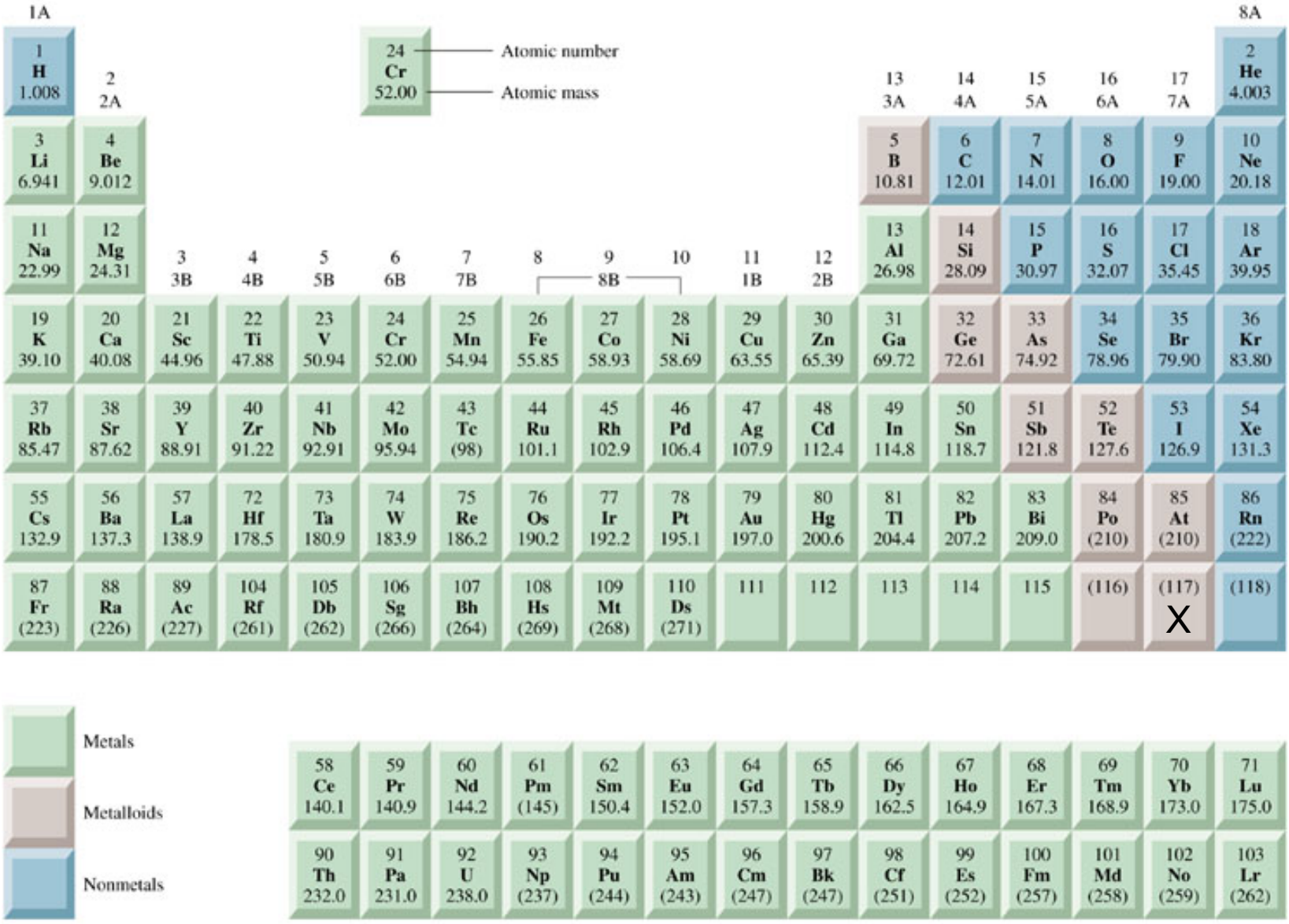
Particle	Relative Charge	Relative Mass	Actual Mass, kg
proton	+1	1	1.67×10^{-27}
neutron	0	1	1.67×10^{-27}
electron	−1	0*	9.11×10^{-31}

Protons & neutrons are in the nucleus (small and dense)
& electrons take up most of the space of atoms but are very light & difficult to describe
Atoms have same # of protons as electrons (zero net charge)

How many protons/electrons are in an atom of Si? 14

What is the element with 17 protons? Cl

The Periodic Table

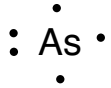


Draw the Lewis structure for:

Br 

As 

Mg 

Te 

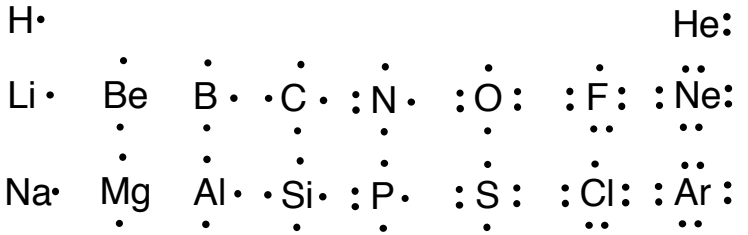
Si 

Lewis Dot diagrams

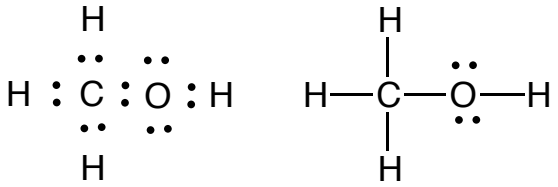
Basic procedure:

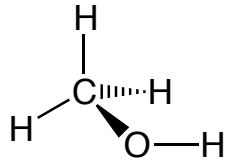
1. Determine # outer/valence electrons for each atom (chapter 2)
2. Arrange outer/valence electrons so each atom has noble gas configuration (chapter 2)
3. Electrons repel (but are attracted to protons) so want to be as far apart as possible (chapter 3)

4 pairs of electrons: tetrahedral
3 pairs of electrons: trigonal planar
2 pairs of electrons: linear

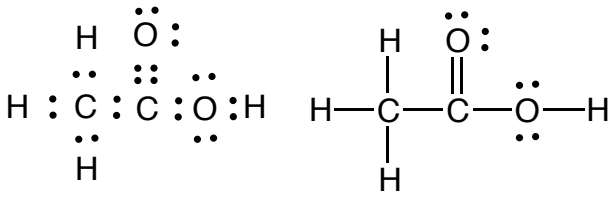


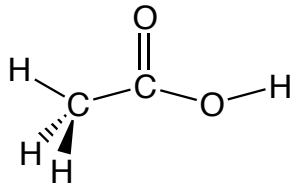
Methanol (CH_4O)



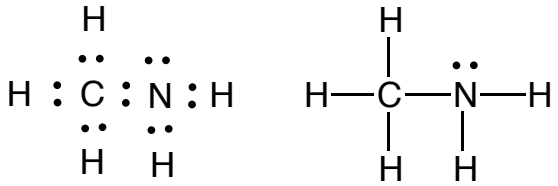


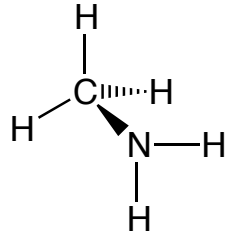
Acetic Acid (CH_3COOH)



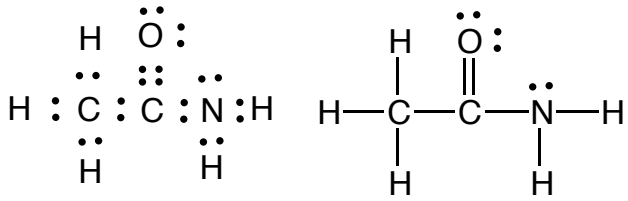


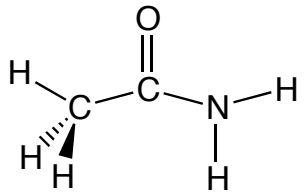
Methyl amine (CH_3NH_2)





Acetamide (CH_3CONH_2)





Molar mass, factor-label/unit conversions

What's the molar mass of:

N_2O

2x14.01
+16.0
=44.02 g/mol

freon-12 (CF_2Cl_2)

2x19.00
+2x35.45
+12.01
=120.91 g/mol

ethanol (C_2H_6O)

2x12.01
+6x1.01
+16.00
=46.08 g/mol

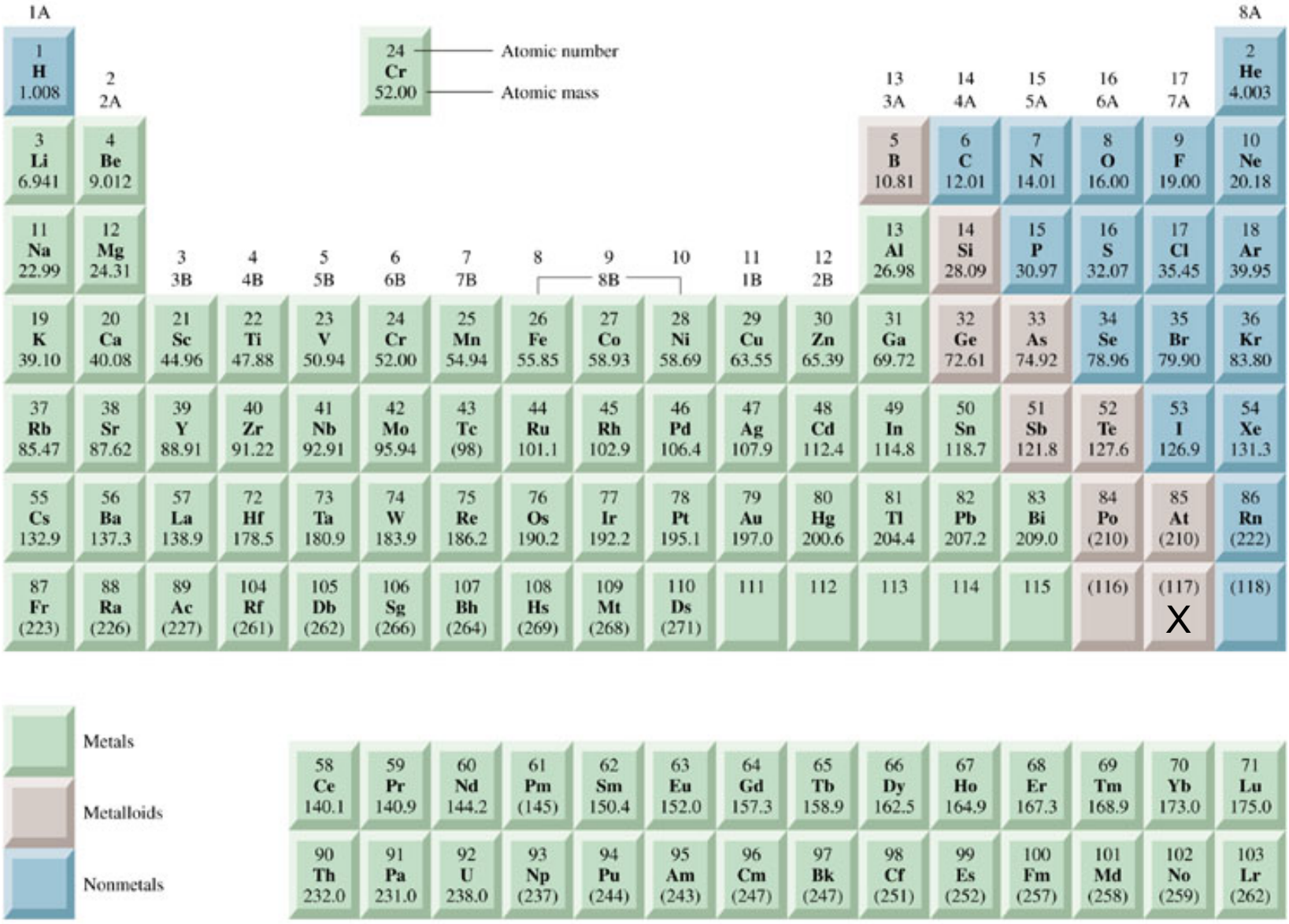
glucose ($C_6H_{12}O_6$)

6x12.01
+12x1.01
+6x16.00
=180.18 g/mol

water (H_2O)

2x1.01
+16.00
=18.02 g/mol

The Periodic Table



Water Solutions & Acids & Bases

- Concepts water
  - electronegativity ➔polar bonds ➔ polar molecules (sometimes)
  - hydrogen bonding: effects on melting and boiling points; effects on solubility
  - ions and ionic compounds
    - anions (-)
    - cations (+)
    - polyatomic ions

    Compounds neutral (no net charge)
    so subscripts are chosen to have zero net charge
  - concentration terms
    - ppm = mg solute /L H_2O
    - ppb = µg solute /L H_2O
    - molarity (M) = mol solute/L solution grams ➔ moles

- Concepts Acids & Bases
  - definitions of acids and bases
    - acids produce hydronium ion [H_3O^+] when dissolved in aqueous solutions
    - bases produce hydroxide ion [OH^-] when dissolved in aqueous solutions
  - acid-base equilibria and neutralization
    - acid + base → salt + water
    - [H_3O^+] * [OH^-] = 1 x 10^{-14} (a constant)
  - definition of pH
    - pH = -log[H_3O^+] [H_3O^+]=10^{-pH}

Where does our drinking water come from?

Surface water: lakes, rivers, reservoirs
Ground water: aquifers

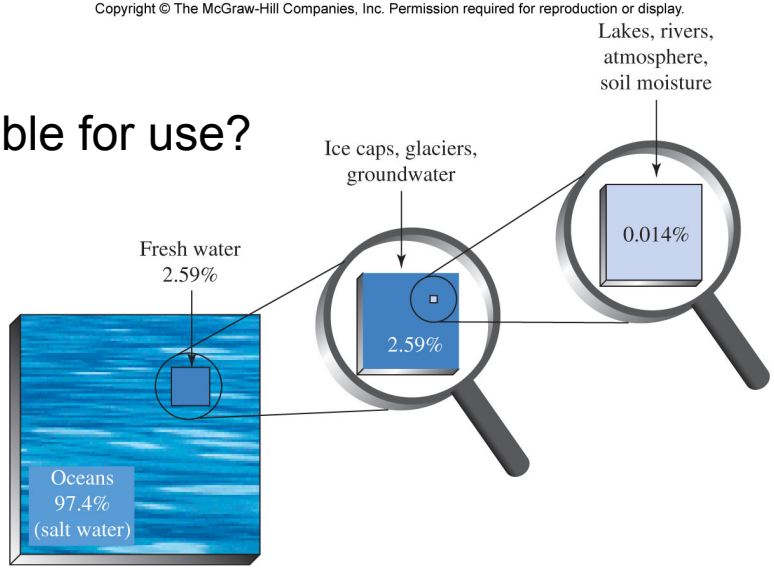
How much water is there in the world?

3.7×10^{20} gallons, 1.4×10^{21} kg

What fraction of the world's water is available for use?

97.4% in oceans
2.59% fresh water
2% ice caps & glaciers
0.014% in lakes, rivers, and soil

5.2×10^{16} gallons, 2.0×10^{17} kg



How much do we use?

In 2000 US water usage (10^9 gallons/day):
194 thermal electric power
137 irrigation
43 domestic
19 Industrial
14 Misc

What Physical Properties of Water did we talk about?

Bonds are polar (electronegativity)
Molecule is polar
Hydrogen bonding (~22 kJ/mol) (large heat capacity, why we use water for heating and cooling)

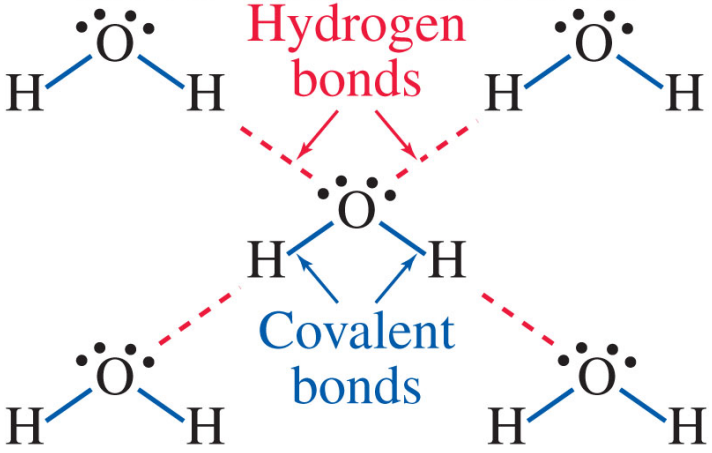


Table 5.3 Electronegativity Values, Arranged by Group Number

1A	2A	3A	4A	5A	6A	7A	8A
H							He
2.1							—
Li	Be	B	C	N	O	F	Ne
1.0	1.5	2.0	2.5	3.0	3.5	4.0	—
Na	Mg	Al	Si	P	S	Cl	Ar
0.9	1.2	1.5	1.8	2.1	2.5	3.0	—

Molarity (M)

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{L of solution}}$$

One reagent bottle on the shelf in a laboratory is labeled 12 M H_2SO_4 & another bottle on the shelf in a laboratory is labeled 12 M HCl.

How does the number of moles of H_2SO4 in 100 mL of 12 M H_2SO4 solution compare with the number of moles of HCl in 100 mL of 12 M HCl solution?

They are the same, 1.2 moles

How does the number of grams of H_2SO4 in 100 mL of 12 M H_2SO4 solution compare with the number of grams of HCl in 100 mL of 12 M HCl solution?

They are not the same, because the molar masses are different.

H_2SO_4: 2x1.0+32.1+4x16.0=98.1 g/mol→ 98.1g/molx1.2moles=117.7 g
HCl: 1.0 +35.5=36.5 g/mol→ 36.5g/molx1.2moles=43.8 g

What do we know about Ionic compounds?

form ions when dissolved in water
have noble gas configurations (can use this to figure out charges & formulas)

What is the formula for calcium bromide?

$Ca \rightarrow Ca^{2+}$
$Br \rightarrow Br^{-}$ $\rightarrow CaBr_2$

What's the rule for solvation?

Like dissolves like
Polar dissolves in polar, non-polar dissolves in non-polar

How can we purify salt water?

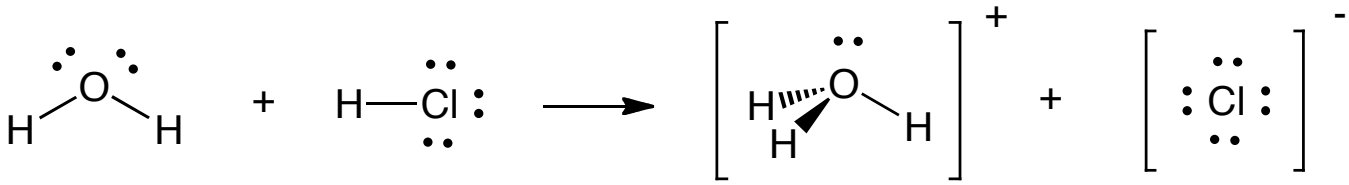
Distillation
Reverse osmosis

Both take energy

What do we know about acids?

Acids are sour

Acids produce hydronium ion H_3O^+ when dissolved in H_2O solution



Noble gas configuration maintained

Acids tend to produce the mono & polyatomic anions we talked about in chapter 5

What do we know about bases?

Bases are bitter

Bases produce hydroxide ion OH^- when dissolved in H_2O solution

Bases tend to produce the mono & polyatomic cations we talked about in chapter 5

$NaOH \rightarrow Na^+(aq) + OH^-(aq)$

$NH_3(aq) + H_2O \rightarrow NH_4^+(aq) + OH^-(aq)$

What is neutralization?

An acid reacting with a base to make a solution where $[H_3O^+]=[OH^-]$

$[H_3O^+][OH^-]=1x10^{-14}$ at 25˚C

In a neutral solution $[H_3O^+]=[OH^-]=1x10^{-7}$

if $[H_3O^+]>[OH^-]$ acidic solution	if $[H_3O^+]=1x10^{-6}$ then $[OH^-]=1x10^{-8}$	acidic
if $[H_3O^+]<[OH^-]$ basic solution	if $[H_3O^+]=1x10^{-11}$ then $[OH^-]=1x10^{-3}$	basic

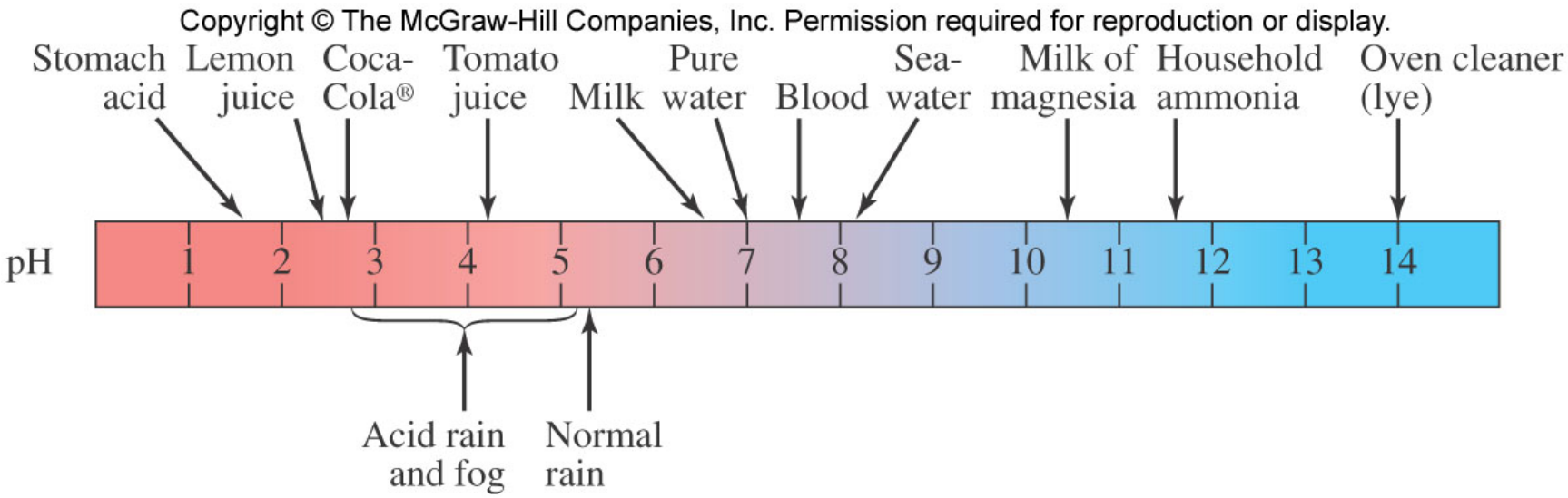
What's pH & why do we care?

pH stands for power of hydrogen
$pH=-\log[H_3O^+]$ (negative of the power of 10)

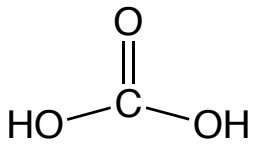
if $[H_3O^+]=1x10^{-3}$ then pH=3
if $[H_3O^+]=1x10^{-8}$ then pH=8
if $[H_3O^+]=1x10^{-7}$ then pH=7

We care because acidic and basic solutions can catalyze the breakdown of biological as well as non-biological compounds
We saw proteins & fats (cell membranes)
We also saw marble ($CaCO_3$) and iron (forms rust)

Is rain normally acidic?

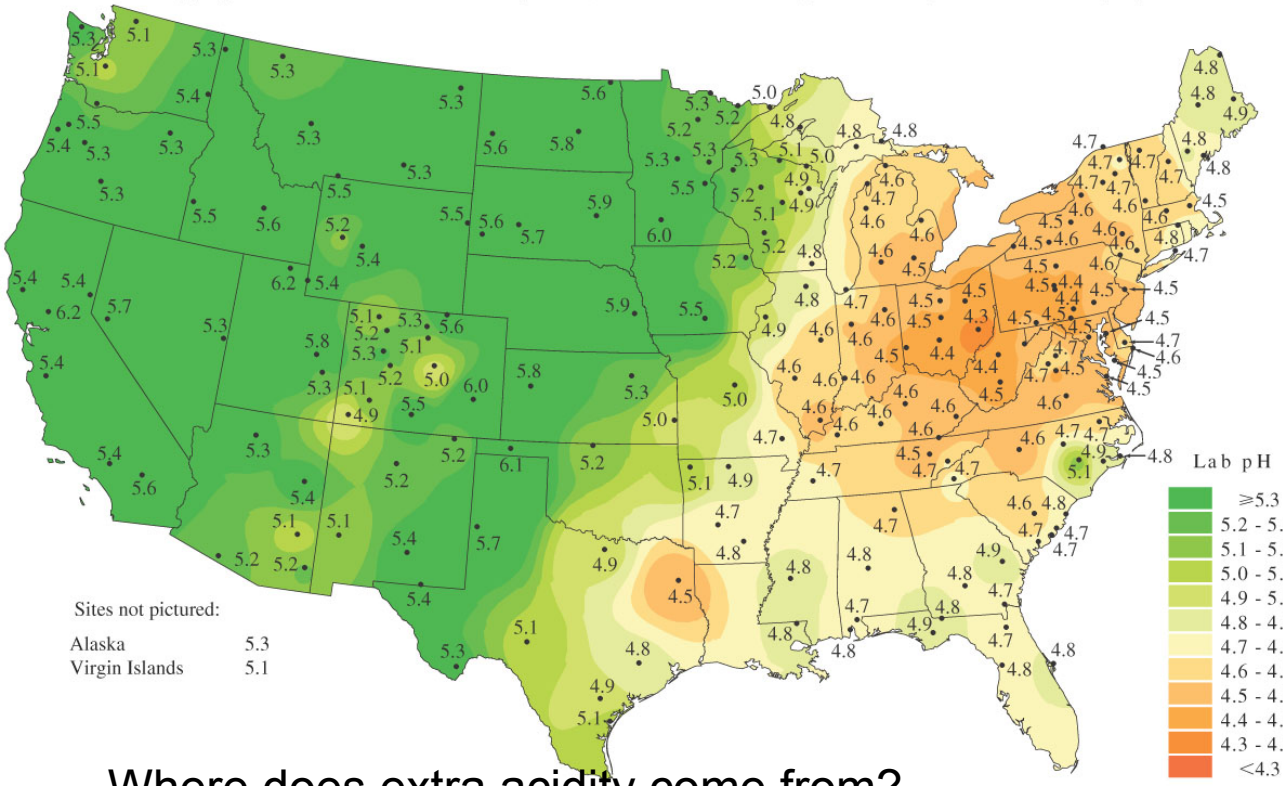


Remember: $CO_2 + H_2O \rightleftharpoons H_2CO_3$



$H_2CO_2 + H_2O \rightleftharpoons H_3O^+ + HCO_3^-$ This leads to a pH 5.6 solution

$HCO_2^- + H_2O \rightleftharpoons H_3O^+ + CO_3^{2-}$



Where does extra acidity come from?

coal $2C_{135}H_{96}O_9NS + 313O_2 \rightarrow 270CO_2 + 96H_2O + 2NO_2 + 2SO_2$

In atmosphere: $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ Sulfuric acid

$H_2SO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$ hydrogen sulfate ion

$HSO_4^-(aq) + H_2O(l) \rightarrow H_3O^+(aq) + SO_4^{2-}(aq)$ sulfate ion

NO_2 formed when any combustion occurs (from N_2 in air)

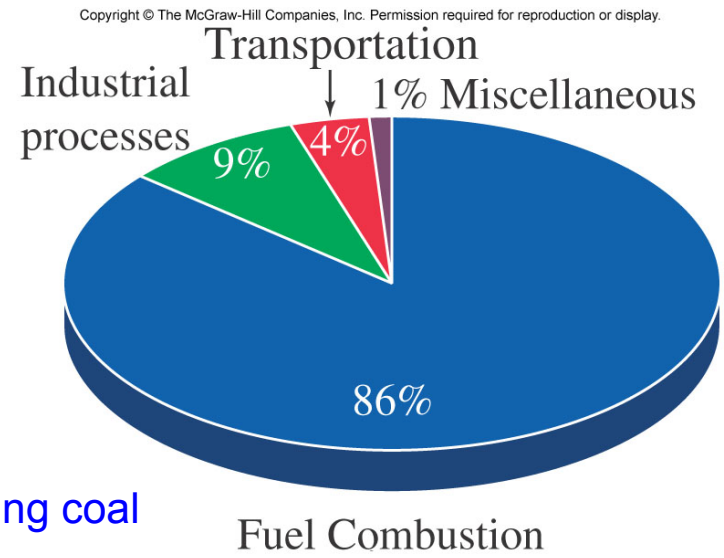
$4NO_2(g) + 2H_2O(l) + O_2(g) \rightarrow 4HNO_3(aq)$ Nitric acid

$HNO_3(aq) + H_2O(l) \rightarrow H_3O^+(aq) + NO_3^-(aq)$ nitrate ion

Where does most of the SO_2 come from?

Burning coal (86%)
Smelting ore (9%)

Smelting ore
$NiS + O_2 \rightarrow Ni + SO_2$



burning coal

Where does most of the NO_2 come from?

Transportation (56%)
Burning coal (38%)