Fundamental Skills Review

Introductory Chemistry I (McMaster University)

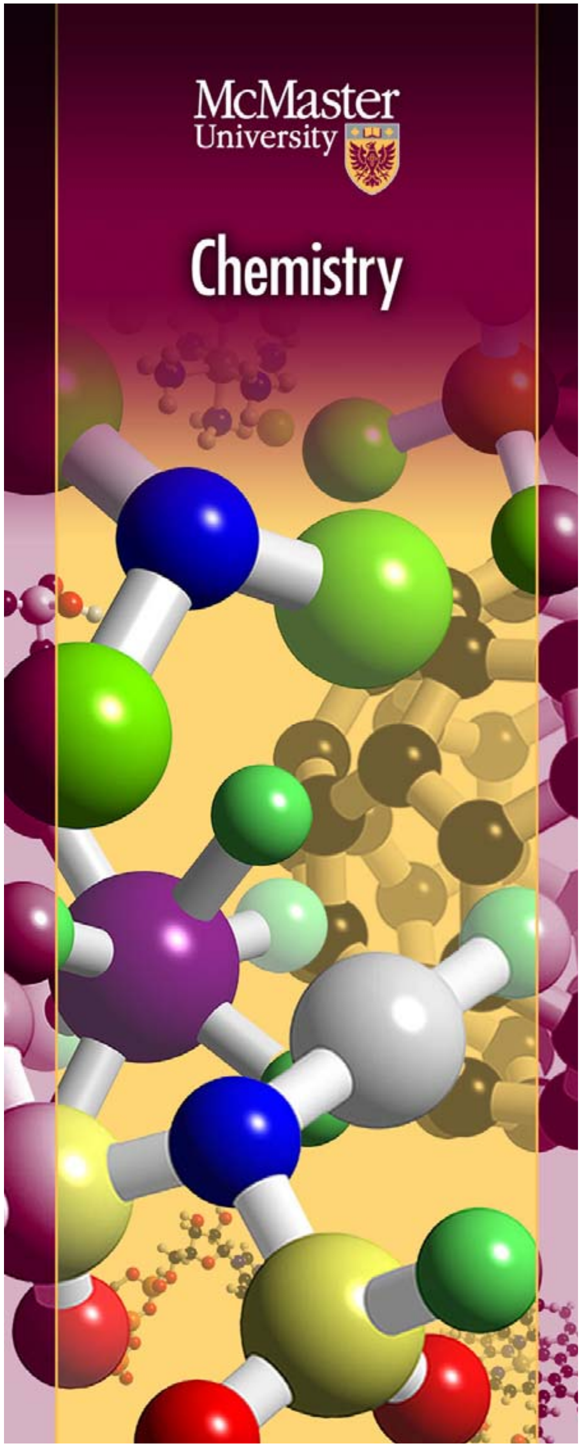
Chemistry 1A03
Introductory Chemistry I

Chemistry in the context of health, energy and the environment

Fundamental Skills Review -

Highlights of selected

topics from Ch 1-4, 6



Chemistry – It's Elemental! (2-6)

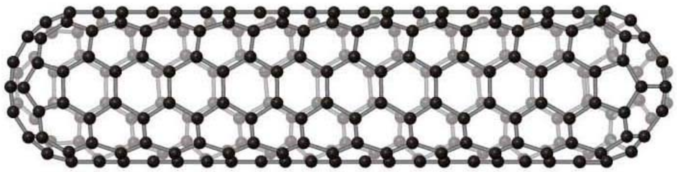
1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 H 1.00794																	2 He 4.00260
3 Li 6.941	4 Be 9.01218											5 B 10.811	6 C 12.0107	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.1797
11 Na 22.9898	12 Mg 24.3050											13 Al 26.9815	14 Si 28.0855	15 P 30.9738	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.9380	26 Fe 55.845	27 Co 58.9332	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.409	31 Ga 69.723	32 Ge 72.64	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.798
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.904	54 Xe 131.293
55 Cs 132.905	56 Ba 137.327	57–71 La–Lu	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.084	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89–103 Ac–Lr	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Rg (272)							

*Lanthanide series	57 La 138.905	58 Ce 140.116	59 Pr 140.908	60 Nd 144.242	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.925	66 Dy 162.500	67 Ho 164.930	68 Er 167.259	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
†Actinide series	89 Ac (227)	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

▲ FIGURE 2-15
Periodic table of the elements

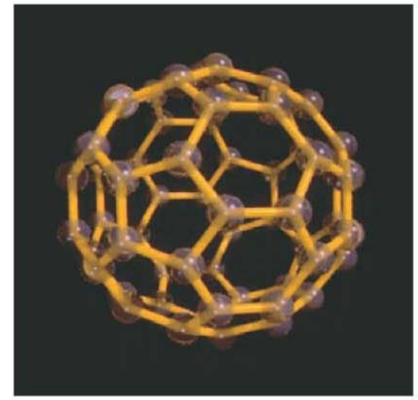
Period = ?   Group = ?   Colours = ?

Elements at work…

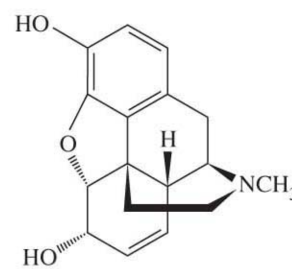


Chemistry - materials

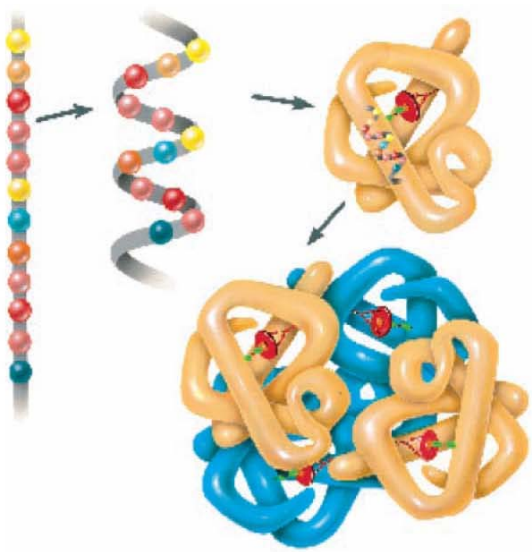
Chemistry - molecules

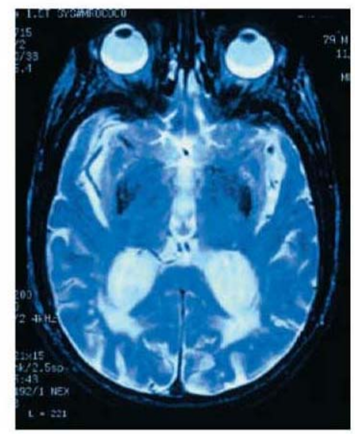


Chemical biology



Morphine





Chemistry…

Biochemistry

Biology…and more

Elements at work and play…

C

Ne

K, H

He

S

Br

Oxidation State or Ox. Number (3-4)

- actual charge of a monatomic ion

  Cl^- (-1), Mg^{2+} (+2)

- hypothetical charge of an atom in a molecule or polyatomic ion

  CO_2 (C = +4, O = -2)

  SO_4^{2-} (S = +6, O = -2)

- Rules for assigning O.S. (O.N):

  Table 3.2 (p. 85, 10th ed.)

Oxidation Numbers - Exercise

- Assign an oxidation number (O.N.) to each atom:

Cl_2	0	O.N. element = 0
Na_2O	+1, -2	Grp 1, 2 metals = O. N. +1, +2
ClO_4^-	+7, -2	O is usually -2
		sum of O.N. = overall charge
PF_3	+3, -1	F is -1
H_2S	+1, -2	H is usually +1
NaH	+1, -1	except in metal hydrides
H_2O_2	+1, -1	O = -1 in peroxides

Nomenclature (3-6)

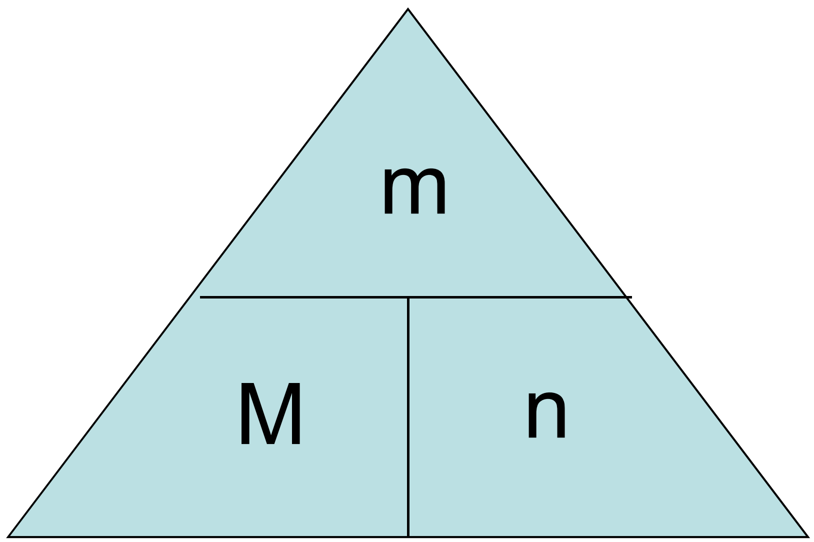
- Simple ions – recognizing O.N.
  Fe(II), Fe^{2+} vs. Fe(III), Fe^{3+}
- Ionic compounds – Table 3-3
  NaCl sodium chloride
- Binary molecular compounds – Table 3-4
  N_2O_3 dinitrogen trioxide
- Polyatomic ions – Table 3-5
  CrO_4^{2-} chromate ion
- Oxoacids & Their Salts – Table 3-6; binary acids
  HClO, ClO^- hypochlorous acid, hypochlorite ion

Mole/mass (2-7)

$6.022_{14199} \times 10^{23}$ mol^{-1} Avogadro's number

mass 1 H atom = 1.0079 amu

mass 1 **mol** H atoms = 1.0079 g mol^{-1}



$m = M \times n$

$M = m / n$

$n = m / M$

molar Mass (M) = mass (m) / mole (n)

Mole/mass – Exercise (2-8)

Calculate the number of Cu atoms present in a copper penny weighing 2.4149 g.

Data needed? $M = 63.546\ \text{g mol}^{-1}$ for Cu

1mol Cu = 6.022×10^{23} Cu atoms

Estimate: Less than 1 mol (approx. 1/30 of a mole)

Solution: $$2.4149\ \text{g Cu} \times \frac{1\ \text{mol Cu}}{63.546\ \text{g Cu}} \times \frac{6.0221 \times 10^{23}\ \text{atoms Cu}}{1\ \text{mol Cu}}$$

= 2.2885×10^{22} Cu atoms

Dimensional analysis (use the units to help you)

Representations of Structure (3-1)

- Ionic compounds:

cations (M^+) + anions (X^-) $\rightarrow$ formula unit (MX)

- Exercise: write the formula unit for:

	Groups	
sodium chloride	1, 17	$NaCl$
potassium sulfide	1, 16	K_2S
magnesium fluoride	2, 17	MgF_2

Representations of Structure

- Molecules:

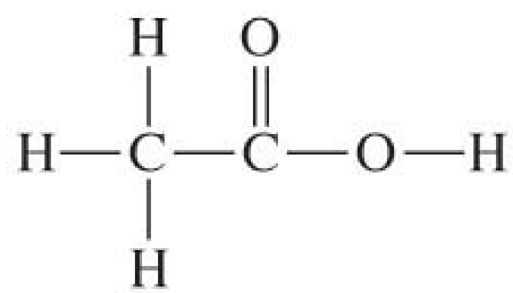
Empirical formula

CH_2O simplest atom ratio

Molecular formula

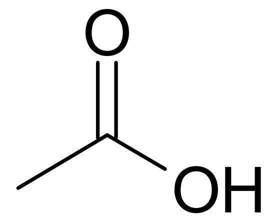
$C_2H_4O_2$ actual atom ratio

Structural formula (connectivity)

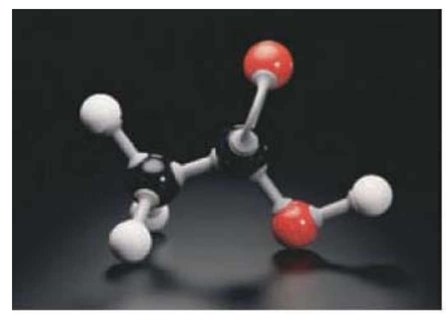


Representations of Structure

- Condensed structural formula CH_3COOH
- Line-angle stick formula



- "Ball and stick" molecular model



- Space filling

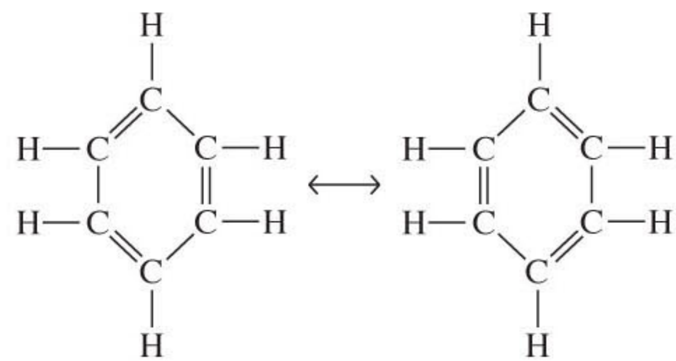
Representations of Structure - Exercise

- For benzene, write:

Empirical formula: CH

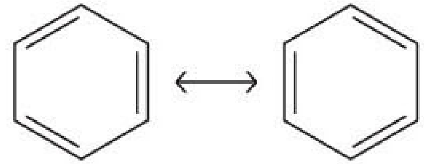
Molecular formula: C_6H_6

Structural formula:



Condensed structural formula: $(CH)_6$

Line-angle stick formula:



Isotopes (2-3, 2-4)

$$ {}^{A}_{Z}E $$

Z = atomic # (# p) - What element is it?

A = mass # (# n + p) - What isotope is it?

e.g. ${}^{16}_{8}O$, ${}^{17}_{8}O$, ${}^{18}_{8}O$ stable isotopes of O

${}^{1}_{1}H$, ${}^{2}_{1}H$ stable isotopes of H

electrons = # protons neutral atom

electrons ≠ # protons charged ion

Isotopes

- Isotopes have natural abundance
  e.g. ^{16}O = 99.76%, ^{18}O = 0.2%
- Samples that show variations from natural isotope abundance can provide key information

Antarctic ice sheet core – contains trapped gases, trace elements, water…

p. 278, Petrucci 10th ed.

Isotopes: Application - Global Warming

- "H_2O" exists in many forms because of multiple stable H and O isotopes

  e.g. $^{1}H_2{}^{16}O$, $^{2}H_2{}^{16}O$, $^{1}H^{2}H^{16}O$, $^{1}H_2{}^{18}O$…

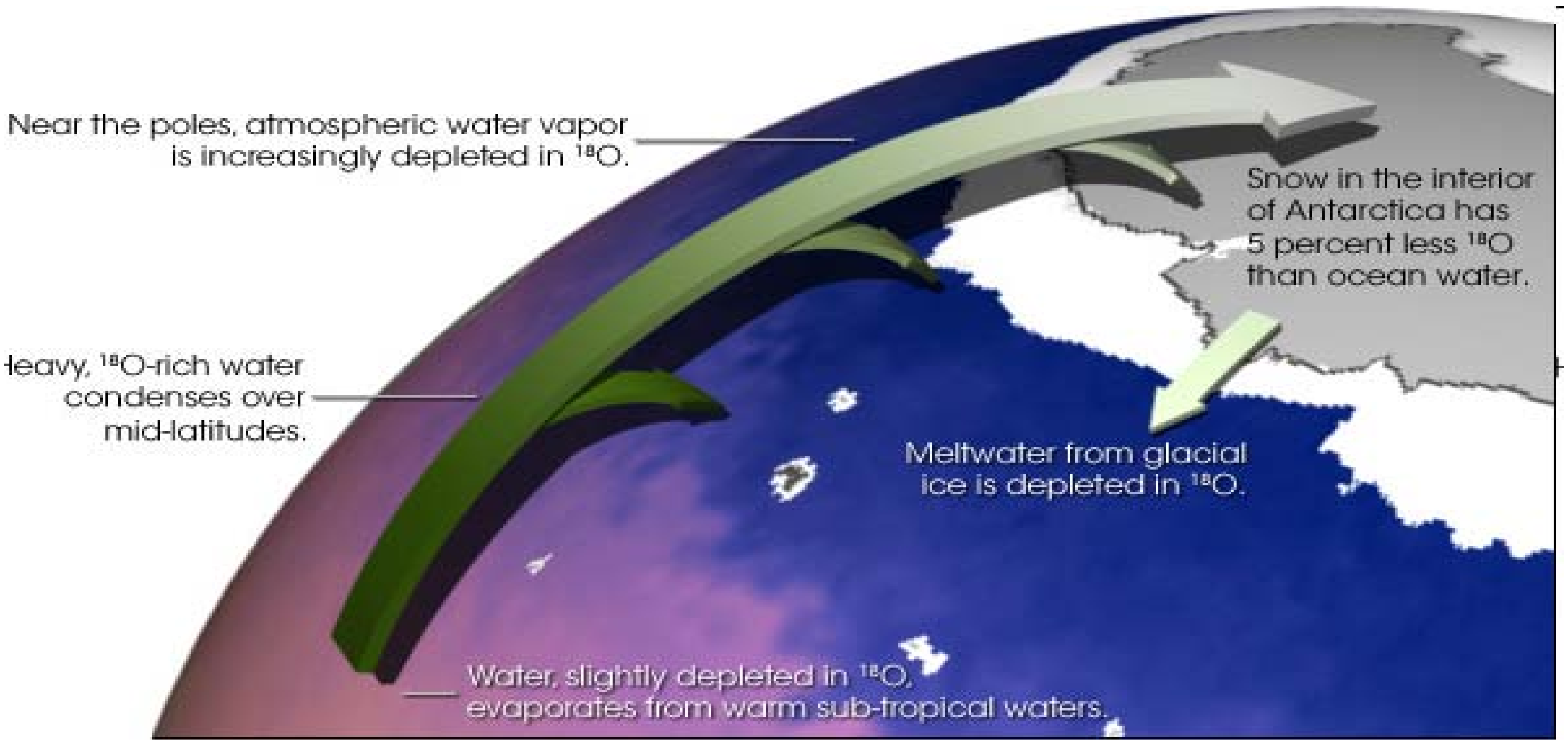
- $H_2O(l)$ (rain!) is richer in heavier forms which condense more readily, especially at lower T

- Measuring $^{18}O/^{16}O$ ratios in ice cores lets us 'measure' past world T (with data calibrated against the recent past) – evidence for global warming

- It's a "climate proxy" (preserved physical characteristic of the past)

Isotopes: Application - Global Warming

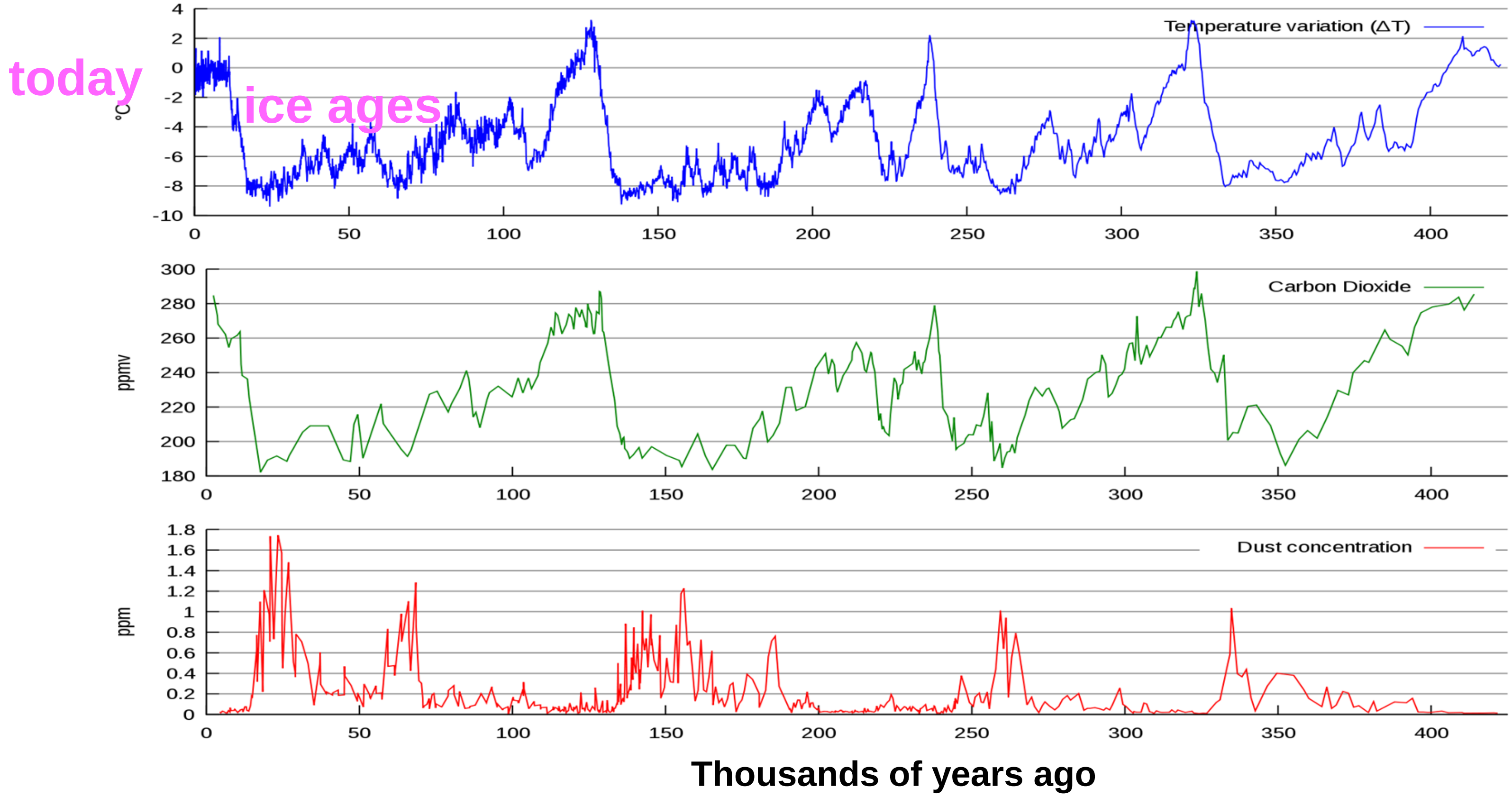
- Depletion of heavy water from snow at earth poles = greater when Earth cooler



http://earthobservatory.nasa.gov/Features/Paleoclimatology_OxygenBalance/ (illustration by Robert Simmon, NASA GSFC)

Ice core – Vostok station, Antarctica

T, CO_2 and dust concentrations



http://en.wikipedia.org/wiki/File:Vostok_Petit_data.svg

CO_2 levels increased 600 (±400) y <u>after</u> T increases during deglaciation periods (slight time lag); currently 360 ppmv

Temperature scales (1-4)

- Kelvin, Celsius scales
- 0 K = absolute zero
- 0°C = ? K = 273 K relative scales

14°C = 287 K

15°C = 288 K

For Celsius, ΔT = 1

For Kelvin, ΔT = 1

ΔT has the same value, regardless of T scale

- Be careful with T conversions!

Extensive/Intensive Quantities (1-5)

- Extensive properties: depend on the amount of substance involved

  e.g. m, V, heat capacity

  heat (q) – heat scales with amount of substance

  however, heat characterizes a process undergone by a substance - it is not a property of a substance

- Intensive properties: independent of the amount of substance involved

  e.g. T, d, specific heat capacity, P

  P is an intensive, not extensive, property (e.g. consider atmospheric pressure – a reading independent of how much outside air we “measure”; this is a similar idea to temperature)

Significant Figures (1-7)

- Which figures are significant? Why?

10.02	All
1.00	All
0.054	5, 4 (0, 0 = placeholders)
3400 $= 3.4 \times 10^2$	3, 4 (can't assume zeroes are)
3400.	3, 4, 0, 0 (because of decimal)
pH = 10.02	The decimals only*

*see podcast on handling logs and sig figs!

http://www.chemistry.mcmaster.ca/undergraduate-/podcasts

Sig. Figs. Guidelines - Exercise

- Determine the number of significant figures in each answer (no calculation required!)

10.01 x 12.3 = 123 3 (lowest # of s.f. for multiplication)

9.52 / 1.614 = 5.90 3 (lowest # of s.f. for division)

1.1 + 12.11 = 13.2 3 (smallest # of decimals for add/subtract)

- Round to 2 decimals:

1.065 = 1.07 (5-9 = round up)

1.044 = 1.04 (0-4 = round down)

iClicker question – Sig. Figs.

- Which of the following has 4 significant figures?

(A) 0.123

(B) 0.056

(C) 3560

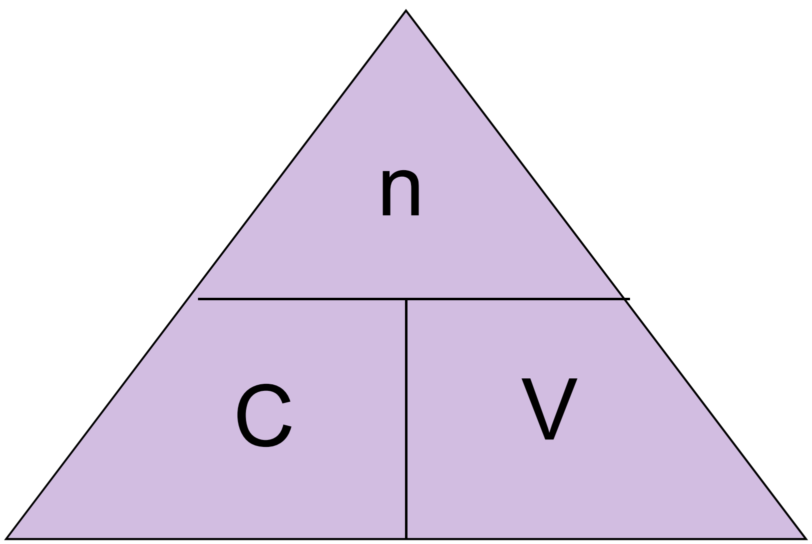
(D) 21.18

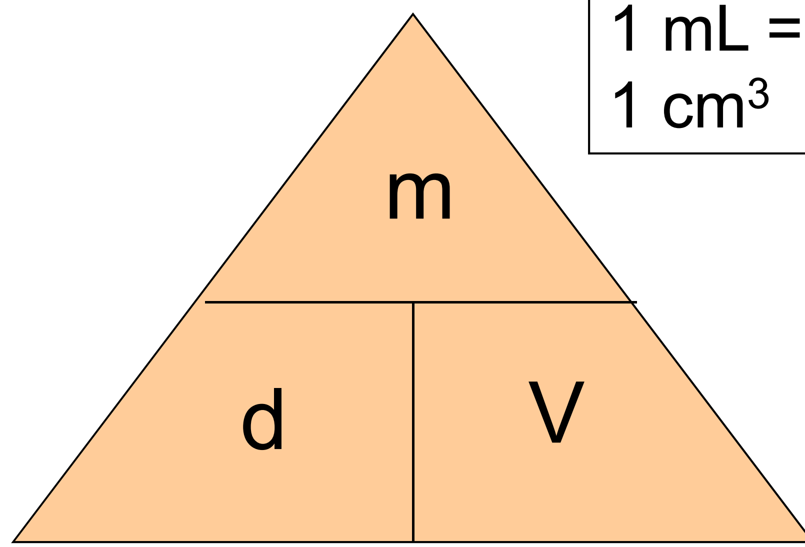
(E) Both (C) and (D)

Concentration & Density (4-3)

- concentration, C = mol (n) / volume (V)
- density, d = mass (m) / volume (V)

Recall:
1 mL =
1 cm^3





n = C x V

C = n / V

V = n / C

m = d x V

d = m / V

V = m / d

Solution, % mass, % volume

% by mass = mass of solute / mass of solution × 100

% by volume = volume of solute / volume of solution × 100

Exercise: An HCl solution is 28.0% by mass, and has density of 1.14 g/mL. What is the concentration of the solution?

Answer: Require C = n/V. Assume 100.g solution, thus 28.0 g HCl.

mol HCl = 28.0 g HCl × (1 mol HCl / 36.46064 g HCl) = 0.76795 mol

Volume solution = 100 g solution × (1 mL solution / 1.14 g solution) = 87.72 mL or 0.08772 L

C = n/V = 0.76795 mol / 0.08772 L = 8.7546 M = 8.75M

Note: 'M' here is molarity (mol/L) and not molar mass.

Stoichiometry & Yield (4-1, 4-2, 4-4)

- Balance the following reaction:

  $NO(g) + O_2(g) \rightarrow NO_2(g)$

- Balanced reaction:

  $2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$ or

  $NO(g) + \frac{1}{2}\ O_2(g) \rightarrow NO_2(g)$

- If we react 1.8 mol NO(g) and 1 mol O_2(g), what is the limiting reagent?

  NO(g)

Stoichiometry & Yield (4-5)

$$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$$

- From 1.8 mol NO(g) and 1 mol O_2(g) what is the theoretical yield (mol) of NO_2(g)?

  1.8 mol, since NO is limiting reagent, and there is a 1:1 ratio of NO:NO_2

- If we actually get 1.6 mol NO_2(g), what is the percent yield?

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\,\% = \frac{1.6}{1.8} \times 100\,\% = 89\,\%$$

Chemical Reactions

- Complete/balance as many reactions as you can (1 minute):

$Na(s) + H_2O(l) \rightarrow$ $\qquad\qquad\qquad$ $+ H_2(g)$

$NaOH(aq) + HCl(aq) \rightarrow$

$Pb(NO_3)_2(aq) + K_2SO_4(aq) \rightarrow PbSO_4(s) +$

$Zn(s) + HCl(aq) \rightarrow$ $\qquad\qquad\qquad$ $+ H_2(g)$

Chemical Reactions

Demo, redox

$2\ Na(s) + 2\ H_2O(l) \rightarrow 2\ NaOH(aq) + H_2(g)$

Lab, acid-base

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

Demo, ppt.

$Pb(NO_3)_2(aq) + K_2SO_4(aq) \rightarrow PbSO_4(s) + 2\ KNO_3(aq)$

$Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$ Lab, redox

- Label as acid-base, redox, precipitation?

Chemistry Arrows

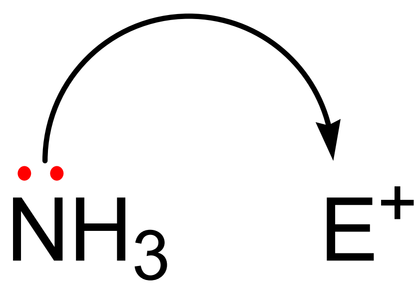
- Different types of arrows tell a different story:

$\longrightarrow$ Reaction

$\longleftrightarrow$ Resonance

$\rightleftharpoons$ Equilibrium

$+\!\!\!\longrightarrow$ Dipole



Electron pair movement

(curly arrow)

Arrows - Exercise

- Complete with correct arrows:

$C(s) + O_2(g) \qquad CO_2(g)$ (combustion)

$2\,NO_2(g) \qquad N_2O_4(g)$ (smog equilibrium)

(benzene resonance)

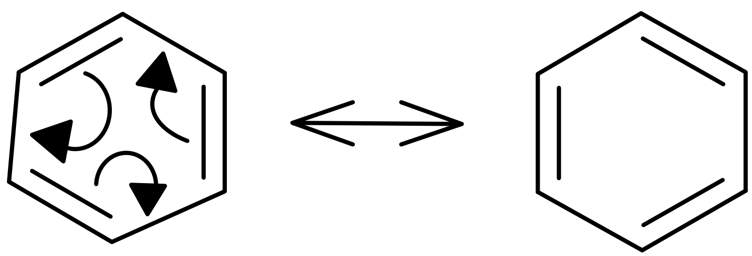
H—Cl (polar bond)

Arrows - Exercise

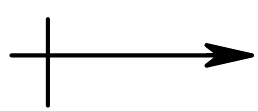
- Complete with correct arrows:

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

$$2\ NO_2(g) \rightleftharpoons N_2O_4(g)$$



$$H-Cl$$



Gas laws (6-3)

- Ideal gas law: $\boxed{PV = nRT}$

- Comes from:

$$V \propto \frac{1}{P}$$ Boyle

$$V \propto T$$ Charles

$$V \propto n$$ Avogadro

Gas laws – rearranging (6-4)

- Starting from the ideal gas law, use d=m/V and M=m/n to produce an equation that involves P, R, T, d, M:

$$PV = nRT$$

Rearrange to isolate n and V

$$\frac{P}{RT} = \frac{n}{V}$$

Now use n = m/M

$$\frac{P}{RT} = \frac{m}{MV}$$

Now use d = m/V

$$\frac{P}{RT} = \frac{d}{M}$$

Partial Pressure (6-6)

- The partial pressure of a gas "A" (P_A) describes its contribution to the total pressure (P_{TOTAL})

$$P_{TOTAL} = P_A + P_B + \ldots + P_N$$

- The partial pressure of a gas is derived from its fractional contribution to the total pressure

mole fraction of A

$$P_A = P_{TOTAL} \times x_A$$

A Case Study

- A truck carrying a full load of cases of Viagra® was hijacked and stolen by thieves. The truck was later recovered, but the Viagra® was gone.

- The Insurance agent handling the case was required, in order to complete their report, to write down an estimated value of the cargo stolen.

- Imagine you are the insurance agent: ***Complete your report.***

The Case: What do we need to know?

- How many cases were on the truck?

  300
- How many packages per case?

  960
- How many pills per package?

  40
- What is the price per pill?

  $2.50/pill

What do we do with the data?

$$300\text{ cases} \times 960\ \frac{\text{packages}}{\text{case}} \times 40\ \frac{\text{pills}}{\text{package}} \times \frac{\$2.50}{\text{pill}}$$

= \$28,800,000 or \$28.8 x 10^6

The value of entire truck load of Viagra® is \$28.8 million.

Note: sig.figs are *not* limited by # *of packages* or *number of pills;* these are *"exact" numbers,* with infinite sig. figs.

Practice Problem #1

C(s) (14.30 g) is combusted with O_2(g) (37.90 g) at 298.15 K and a pressure of 1.00 atm. How many L of CO_2(g) are produced?

Solution:

Reaction: $C(s) + O_2(g) \rightarrow CO_2(g)$

Find limiting reagent: mol C = m/M = 1.191 mol C

Mol O_2 = 37.90 g / 31.9998 g mol^{-1} = 1.184 mol O_2

Since C and O_2 react in a 1:1 ratio, O_2 is the limiting reagent.

Using PV = nRT, rearrange to give V = nRT/P

$$\text{Volume } CO_2 = \text{mol } O_2 \text{ x } \frac{1 \text{ mol } CO_2}{1 \text{ mol } O_2} \text{ x } \frac{RT}{P}$$

Where T = 298.15 K, P = 1.00 atm, R = 0.08206 L atm/K mol

$$V = 1.184 \text{ mol } CO_2 \text{ x } \frac{0.08206 \text{ L atmK}^{-1}\text{mol}^{-1} \times 298.15 \text{ K}}{1.00 \text{ atm}}$$

$$V = 28.9_7 \text{ L} = 29.0 \text{ L}$$

Practice Problem #2

$Pb(NO_3)_2$(aq) (75.2 mL, 0.0500 M) is mixed with KI(aq) (41.6 mL, 0.0800 M), and a precipitate of PbI_2 is formed.

Calculate the amount (g) of PbI_2(s) produced and the amount (mol) of excess reactant that remains.

Solution:

Reaction: $Pb(NO_3)_2(aq) + 2\ KI(aq) \rightarrow PbI_2(s) + 2\ KNO_3(aq)$

mol $Pb(NO_3)_2$ = C × V = (0.0500 mol L^{-1}) (0.0752 L) = 3.76×10^{-3} mol,

mol KI = C × V = (0.0800 mol L-1) (0.0416 L) = = $3.32_8 \times 10^{-3}$ mol

KI is the limiting reagent. From the 1:2 ratio, $2(3.32_8 \times 10^{-3})$ mol KI would be required to consume all the $Pb(NO_3)_2$ present.

mol $Pb(NO_3)_2$ remaining = $3.76\text{x}10^{-3} - 3.32_8\text{x}10^{-3} = 2.096\text{x}10^{-3}$ mol,

= $2.10\text{x}10^{-3}$ mol

mol PbI_2 produced = $3.32_8\text{x}10^{-3}$ mol /2 = $1.66_4\text{x}10^{-3}$ mol

m = n × M = $(1.66_4\text{x}10^{-3}$ g)((461.00894 g/mol) = 0.767 g

Learning Objectives

- For a full list of learning objectives from Ch 1-4, 6, refer to:

  Fundamental Skills Review Learning Objectives list, posted in Avenue

- For additional practice in other types of problems, complete Tutorial #1 (e.g. combustion, percent composition)

- Try a variety of end-of-chapter questions – watch for list of recommended questions in Avenue