2 ATOMS, MOLECULES AND IONS

LECTURE NOTES

Students find this material relatively easy to assimilate; it's almost entirely qualitative. On the other hand, there's a lot of memorizing (sorry, learning) to do. This chapter is coverable in two lectures.

Some general observations:

- Material in Sections 2.1–2.3 is generally well covered in high-school chemistry courses; no need to dwell on it.
- Students need to know the molecular formulas of the elements (Figure 2.13), the charges of ions with noble-gas structures and the names and formulas of the common polyatomic ions (Table 2.2). The charges of transition-metal ions will be covered later, in Chapter 4.
- Naming compounds requires students to distinguish between ionic and molecular substances. It helps to point out that binary molecular compounds are composed of two nonmetals. Almost all ionic compounds contain a metal cation combined with a nonmetal anion or negatively charged polyatomic ion. The flow charts shown in Figures 2.18 and 2.19 should help visual learners.
- The periodic table will be discussed in greater detail later in the text (Chapter 6).

Lecture 1

I. Atomic Theory

A. Elements

Postulates: Elements consist of tiny particles called atoms, which retain their identity in reactions. In a compound, atoms of two or more elements combine in a fixed ratio of small whole numbers (e.g., 1:1, 2:1, etc.).

B. Components

	relative mass	relative charge	location
proton	1	+1	nucleus
neutron	1	0	nucleus
electron	0.0005	−1	outside

C. Atomic number

It is the number of protons in the nucleus or the number of electrons in a neutral atom. This is characteristic of a particular element: all H atoms have one proton, all He atoms have two protons, etc.

D. Mass number

1. It is the sum of the number of protons and the number of neutrons. Atoms of the same element can differ in mass number. Those are referred to as isotopes. For example:

	protons	neutrons	atomic no.	nuclear symbol	mass no.
carbon-12	6	6	6	$^{12}_{6}C$	12
carbon-14	6	8	6	$^{14}_{6}C$	14

2. Isotopes

Atoms of the same element (same atomic number) but differ in mass number.

II. Atomic Masses

A. Meaning of atomic masses

They give the relative masses of atoms. Based on the C-12 scale; the most common isotope of carbon is assigned an atomic mass of exactly 12 amu.

element	B	Ca	Ni
atomic mass (amu)	10.81	40.08	58.69

A nickel atom is 58.69/40.08 times as heavy as a calcium atom. It is 58.69/10.81 = 5.429 times as heavy as a boron atom.

B. Atomic masses from isotopic composition

atomic mass = (atomic mass of isotope 1)(%/100) + (atomic mass of isotope 2)(%/100) + $\cdots$

Isotope	Atomic mass	Percent
Ne-20	20.00 amu	90.92
Ne-21	21.00 amu	0.26
Ne-22	22.00 amu	8.82

atomic mass of Ne = (20.00)(0.9092) + (21.00)(0.0026) + (22.00)(0.0882) = 20.18 amu

C. Masses of individual atoms

Since the atomic masses of H, Cl and Ni are, respectively, 1.008 amu, 35.45 amu and 58.69 amu, it follows that

1.008 g H, 35.45 g Cl, 58.69 g Ni all contain the same number of atoms, N_A.

$$N_A = \text{Avogadro's number} = 6.022 \times 10^{23}$$

1. Mass of a hydrogen atom?

$$1 \text{ atom H} \times \frac{1.008\,\text{g H}}{6.022 \times 10^{23}\,\text{atom}} = 1.674 \times 10^{-24}\,\text{g}$$

2. Number of atoms in one gram of nickel?

$$1.000\,\text{g Ni} \times \frac{6.022 \times 10^{23}\,\text{atoms Ni}}{58.69\,\text{g Ni}} = 1.026 \times 10^{22}\,\text{atoms}$$

III. Periodic Table

Periods and groups; numbering system for groups. Metals appear at the lower left, nonmetals at the upper right. Metalloids.

Lecture 2

IV. Molecules

A. Composition

Usually consist of nonmetal atoms; held together by covalent bonds.

B. Types of Formulas

Consider the compound ethyl alcohol:

Molecular formula: C_2H_6O

Structural formula:
$$\begin{array}{ccccccccc} & & \text{H} & & \text{H} & & & & \\ & & | & & | & & & & \\ \text{H} & - & \text{C} & - & \text{C} & - & \text{O} & - & \text{H} \\ & & | & & | & & & & \\ & & \text{H} & & \text{H} & & & & \end{array}$$

Condensed structural formula: CH_3CH_2OH

V. Ions

A. Formation of monatomic ions

Na atom $(11p^+, 11e^-) \rightarrow$ Na^+ ion $(11p^+, 10e^-) + e^-$

F atom $(9p^+, 9e^-) + e^- \rightarrow$ F^- ion $(9p^+, 10e^-)$

B. Charges of monatomic ions with noble-gas structures

Cations: Group 1 (+1); Group 2 (+2); Al^{3+}

Anions: Group 1**6** (−2); Group 1**7** (−1); N^{3-}

C. Polyatomic ions

Names and formulas (Table 2.2)

D. Formulas of compounds

Apply the principle of electroneutrality.

calcium fluoride:	Ca^{2+}, F^- ions:	CaF_2
aluminum nitrate:	Al^{3+}, NO_3^- ions:	$Al(NO_3)_3$
sodium dihydrogen phosphate:	Na^+, $H_2PO_4^-$ ions:	NaH_2PO_4

E. Ionic compounds

They can be distinguished from molecular substances by the conductivity of their water solutions. Solutions of NaCl, $Ca(OH)_2$, ... conduct electricity (electrolytes). Sugar is a nonelectrolyte.

VI. Names of Compounds

A. Ionic

Name cation, followed by anion. Note that with transition metal cations, charge is indicated by a Roman numeral.

Na_2SO_4 sodium sulfate $Fe(NO_3)_3$ iron(III) nitrate

Systematic names of oxoanions (-ate, -ite, per-, hypo-)

Calcium hypochlorite $Ca(ClO)_2$

B. Binary molecular compounds

Use of Greek prefixes:	SF_6	sulfur hexafluoride
	N_2O_3	dinitrogen trioxide

C. Acids

Binary acids:	hydrochloric acid	
Oxo acids:	-ate salt → -ic acid	$HClO_4$, perchloric acid
	-ite salt → -ous acid	HClO, hypochlorous acid

DEMONSTRATIONS

1. Law of constant composition: GILB A 12
2. Law of conservation of mass: GILB A 16
3. Simulation of Rutherford's experiment: GILB L 7
4. Isotope effects (H_2O, D_2O): GILB M 18
5. Reaction of hydrogen with chlorine: GILB H 38
6. Conductivity of water solutions: SHAK 3 140
7. Breath alcohol detection: J. Chem. Educ. *67* 263 (1990); *71* 158 (1994)
8. Relative masses of atoms (analogy): GILB L 2

SUMMARY PROBLEM

(a) S_8

(b) 16 protons, 16 electrons

(c) no; Al_2S_3 - aluminum sulfide

(d) yes

(e) yes; S_2Cl_2 - disulfur dichloride

(f) $^{34}_{16}S$

(g) group 1**6**, period 3

(h) 20 neutrons

(i) (31.97207)(0.9493) + (32.97146)(0.0076) + (33.96787)(0.0429) + (35.96708)(0.0002) = 32.07 amu

(j) $12.55 \text{ g S} \times \dfrac{1 \text{ mol S}}{32.07 \text{ g}} \times \dfrac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol S}} = 2.357 \times 10^{23} \text{ atoms}$

(k) $1 \times 10^9 \text{ S atoms} \times \dfrac{1 \text{ mol S}}{6.022 \times 10^{23} \text{ atoms}} \times \dfrac{32.07 \text{ g}}{1 \text{ mol S}} = 5.325 \times 10^{-14} \text{ g}$

(l) SO_3 = sulfur trioxide; H_2SO_3 (aq) = sulfurous acid; SO_4^{2-} = sulfate ion; Na_2SO_3 = sodium sulfite

PROBLEMS

1. p. 29

3. (a) Conservation of mass (b) Constant composition (c) neither

5. J. J. Thompson; see p. 29

7. $^{80}_{34}Se$

9. no. of neutrons: $^{36}_{18}Ar$, $^{38}_{18}Ar$, $^{40}_{18}Ar$

11. (a) 92 (b) 143 (c) 92

13. (a) 14 p^+, 16 n, 14 e^-; R = Si

(b) 39 p^+, 50 n, 39 e^-; T = Y

(c) 55 p^+, 78 n, 55 e^-; X = Cs

15. (a) Ca-41, K-41, Ar-41 are isobars; Ca-40, Ca-41 are isotopes

(b) atomic number = number of protons = 20

(c) same mass number

17. (a) $\frac{79.90}{20.18} = 3.959$ (b) $\frac{79.90}{40.08} = 1.994$ (c) $\frac{79.90}{4.003} = 19.96$

19. Ce-140

21. 50%

23. 83.9134(0.0056) + 85.9094(0.0986) + 86.9089(0.0700) + 87.9056(0.8258) = 0.47 + 8.47 + 6.08 + 72.59

average atomic mass = 87.61

25. 107.9 = 106.90509(0.5184) + 0.4816x; x = 109 amu

27. Let x = abundance of the first isotope; abundance of second isotope = 0.9704 − x

$28.0855 = 27.9769\,x + (0.9704 - x)(28.9765) + (0.0296)(29.9738)$

$= 27.9769\,x + 28.1188 - 28.9765\,x + 0.887$

x = 0.921; abundance of first isotope is 92.1%

$0.9704 - x = 0.9704 - 0.921 = 0.0494$; abundance of second isotope is 4.94%

29. Tall peak at mass 64; peak a little over 1/2 as high at mass 66; smallest peak is at mass 67, and the height of the peak at mass 64 is 2.5 times that of the peak at mass 68 .

31. $3 \times 10^{-7}\text{ g} \times \frac{1\text{ mol}}{207.2\text{ g}} \times \frac{6.022 \times 10^{23}\text{ atoms}}{1\text{ mol}} = 9 \times 10^{14}\text{ atoms}$

33. (a) $0.185\text{ g Pd} \times \frac{6.022 \times 10^{23}\text{ atoms}}{106.4\text{ g Pd}} = 1.05 \times 10^{21}\text{ atoms}$

(b) $127\text{ protons} \times \frac{1\text{ atom}}{46\text{ protons}} \times \frac{106.4\text{ g}}{6.022 \times 10^{23}\text{ atoms}} = 4.88 \times 10^{-22}\text{ g}$

35. (a) $0.35744\,\text{mol} \times \dfrac{6.022 \times 10^{23}\,\text{atoms}}{1\,\text{mol}} = 2.152 \times 10^{23}\,\text{atoms}$

(b) $2.152 \times 10^{23}\,\text{atoms} \times \dfrac{(14\,p^{+} + 14\,n + 14\,e^{-})}{1\,\text{atom}} = 9.039 \times 10^{24}$

37. $V_{\text{cube}} = \left(1.25\,\text{in} \times \dfrac{2.54\,\text{cm}}{1\,\text{in}}\right)^3 = 32.0\,\text{cm}^3$

$32.0\,\text{cm}^3 \times \dfrac{0.968\,\text{g}}{1\,\text{cm}^3} \times \dfrac{6.022 \times 10^{23}\,\text{atoms}}{22.99\,\text{g}} = 8.12 \times 10^{23}\,\text{atoms}$

39. (a) K (b) Cd (c) Al (d) Sb (e) P

41. (a) main-group metal (b) transition metal (c) main-group metal (d) metalloid

(e) nonmetal

43. (a) 6 (b) 4 named, 1 not named (c) 0

45. (a) 13 (b) 2 (c) 17, 18

47. (a) C_2H_7N (b) C_3H_8O

49. (a) 14 p^+, 14e^- (b) 21 p^+, 22 e^- (c) 35 p^+, 34e^- (d) 70 p^+, 70 e^-

51.

${}^{19}_{9}F$	0	9	10	9
${}^{31}_{15}P$	0	15	16	15
${}^{57}_{27}Co^{3+}$	+3	27	30	24
${}^{32}_{16}S^{2-}$	−2	16	16	18

53. (a) electrolyte (b) nonelectrolyte (c) nonelectrolyte (d) electrolyte

55. (a) CH_4 (b) CI_4 (c) H_2O_2 (d) NO (e) SiO_2

57. (a) iodine trichloride (b) dinitrogen pentaoxide (c) phosphine

(d) carbon tetrabromide (e) sulfur trioxide

59. KCl, K_2S, $CaCl_2$, CaS

61. (a) $Fe(C_2H_3O_2)_3$ (b) $Ca(NO_3)_2$ (c) K_2O (d) $AuCl_3$ (e) Ba_3N_2

63. (a) potassium dichromate (b) copper(II) phosphate (c) barium acetate
    (d) aluminum nitride (e) cobalt(II) nitrate

65. (a) hydrochloric acid (b) chloric acid (c) iron(III) sulfite
    (d) barium nitrite (e) sodium hypochlorite

67. HNO_2, nickel(II) iodate, Au_2S_3, sulfurous acid, NF_3

69. (a) $Mn(NO_2)_3$; manganese(III) nitrite
    (b) BF_3; boron trifluoride
    (c) $Ca(HCO_3)_2$; calcium hydrogen carbonate

71. (a) In (b) Pb or Sn (c) K (d) Sb

73. (a) ... confirmed the presence of a dense nucleus with protons.
    (b) ... elements arranged according to increasing atomic number.
    (c) ... same number of protons.
    (d) Be_3N_2 is beryllium nitride.

75. $$6.00 \text{ oz salami} \times \frac{1 \text{ g}}{0.03527 \text{ oz}} \times \frac{0.090 \text{ g NaC}_7\text{H}_5\text{O}_2}{100 \text{ g salami}} \times \frac{6.022 \times 10^{23} \text{ molecules NaC}_7\text{H}_5\text{O}_2}{144.1 \text{ g NaC}_7\text{H}_5\text{O}_2}$$
$$\times \frac{1 \text{ atom Na}}{1 \text{ molecule NaC}_7\text{H}_5\text{O}_2} = 6.4 \times 10^{20} \text{ Na atoms}$$

77. (b), (d), (e)

79. 8 □○ molecules; 3 □□ molecules left

81. A square with four circles around it (several of them in a flask with a defined volume)

83. (a) 118 (b) 120 (c) 117 (d) 120 (e) 119

85. first experiment: $\% O = \frac{3.87}{52.30} \times 100 = 7.40$; $\% Hg = 92.60$

second experiment: $\% Hg = \frac{15.68}{16.93} \times 100 = 92.62$; $\% O = 7.38$

87. (a) K, Sr (b) O, F, Ar, S (c) S, K, Sr

(d) S (e) S, O or S, F or O, F (f) Sr, S or Sr, O or K, F

(g) Sr, F (h) K, O or K, S (i) Ar

(j) O, F, Ar

88. A: mass C/mass H = 11.9 ($\approx$ 12) B: mass C/mass H = 2.99 ($\approx$ 3)

ratio for (a) = 2.77 ratio for (b) = 4.67 ratio for (c) = 5.96

(c) is best choice

89. (a) ethane: 18.0 g C/4.53 g H = 3.97 g C/g H ethylene: 43.20 g C/7.25 g H = 5.96 g C/g H

5.96/3.97 = 1.50 = 3/2

(b) CH_2 and CH_3; C_2H_4 and C_2H_6

90. mass $= 13\left(1.6726 \times 10^{-4}\,\text{g}\right) + 13\left(9.1094 \times 10^{-28}\,\text{g}\right) + 14\left(1.6749 \times 10^{-24}\,\text{g}\right) = 4.5204 \times 10^{-23}\,\text{g}$

$V = \frac{4}{3}\pi\left(1.43 \times 10^{-8}\,\text{cm}\right)^3 = 1.22 \times 10^{-23}\,\text{cm}^3$

$d = 4.5204\,\text{g}/1.22\,\text{cm}^3 = 3.71\,\text{g}/\text{cm}^3$

Empty space between Al atoms.

91. $2.3440 \times 10^{-23}\,\text{g} + 3(9.1095 \times 10^{-28}\,\text{g}) = 2.3443 \times 10^{-23}\,\text{g}$

92. (a) $200\ \text{inhalations} \times \frac{500\ \text{mL}}{1\ \text{inhalation}} \times \frac{2.5 \times 10^{19}\ \text{molecules}}{1\ \text{mL}} = 2.5 \times 10^{24}\ \text{molecules}$

(b) $\frac{2.5 \times 10^{24}}{1.1 \times 10^{44}} = 2.3 \times 10^{-20}$

(c) $1\ \text{inhalation} \times \frac{500\ \text{mL}}{1\ \text{inhalation}} \times \frac{2.5 \times 10^{19}\ \text{molecules}}{1\ \text{mL}} \times 2.3 \times 10^{-20} = 2.8 \times 10^{2}\ \text{molecules}$

93. Total mass before reaction: 18.00 g + (25.00 x 1.025 g/mL) = 43.63 g

After reaction following the law of conservation of mass: 43.63 g = 12 g + 30.95 g + mass of H_2

mass of H_2 = 0.68 g; volume of H_2 = 0.68 g x $\frac{1\ \text{L}}{0.0824\ \text{g}}$ = 8.25 L