Chapter 2  
Atoms, Molecules, and Ions

Instructor’s Notes

Although much of this chapter will be review for many students who have taken high school chemistry, the ideas included are so central to later study that class coverage will probably be necessary. Key topics are the structure of the atom and related information (atomic number, isotopes), the mole unit, the periodic table, chemical formulas and names, and the relationships between formulas and composition. Three to five class periods will probably be necessary in order to address the essentials in this chapter unless your students are well-versed in some of these topics.

Some points on which students have some problems or questions are:

(a) The rule of determining the charges on transition metal cations tells students that they can assume such ions usually have 2+ or 3+ charges (with 2+ charges especially prominent). They are often uneasy about being given this choice. We certainly emphasize that they will see other possibilities (and that even negative charges are possible but that they will not see them in the general chemistry course).

(b) Students have to be convinced that they have no choice but to learn the language of chemistry by memorizing the names and charges of polyatomic ions. They can be reminded that correct names and formulas are required to prevent serious consequences, such as the use of the wrong medicine which can have tragic results or the purchase of the wrong substance which leads to wasted resources.

(c) A very common problem students have is recognizing that MgBr2, for example, is composed of Mg2+ and two Br– ions. We have seen such combinations as Mg2+ and Br22–.

Suggested Demonstrations

1. Properties of Elements

* Take as many samples of elements as possible to your lecture on the elements and the periodic table.
* See the series by Alton Banks in the *Journal of Chemical Education* titled “What's the Use?” This series describes a different element each month and gives references to the *Periodic Table Videodisc*.
* Pinto, G. “Using Balls from Different Sports to Model the Variation of Atomic Sizes,” *Journal of Chemical Education* **1998**, *75*, 725.

2. Atomic Structure

* Hohman, J. R. “Introduction of the Scientific Method and Atomic Theory to Liberal Arts Chemistry Students,” *Journal of Chemical Education* **1998**, *75*, 1578.

3. Elements That Form Molecules in Their Natural States

* Use samples of H2, O2, N2, and Br2 to illustrate elements that are molecules.

4. Formation of Compounds from Elements and Decomposition of a Compound into Its Elements

* Bring many samples of compounds to your lecture. Ignite H2 in a balloon or burn Mg in O2 to show how elements are turned into compounds. Also burn Mg in CO2 to show CO2 is made of C and that MgO can be made another way.

5. Ionic Compounds

* Bring a number of common, ionic compounds to class.

6. The Mole Concept

* To illustrate the mole, take 1 molar quantities of elements such as Mg, Al, C, Sn, Pb, Fe, and Cu to the classroom.
* When doing examples in lecture, it is helpful to have a sample of the element available. For example, hold up a pre-weighed sample of magnesium wire and ask how many moles of metal it contains. Or, drop a pre-weighed piece of sodium metal into a dish of water on the overhead projector, and ask how many moles of sodium reacted.

7. Molar Quantities

* Display molar quantities of NaCl, H2O, sugar, and common ionic compounds. Especially show some hydrated salts to emphasize the inclusion of H2O in their molar mass.
* Display a teaspoon of water and ask how many moles, how many molecules, and how many total atoms are contained.
* Display a piece of CaCO3 and ask how many moles are contained in the piece and then how many total atoms.

8. Weight Percent of Elements

* When talking about weight percent of elements, use NO2 as an example and then make NO2 from Cu and nitric acid.

9. Determine the Formula of a Hydrated Compound

* Heat samples of hydrated CoSO4 or CuSO4 to illustrate analysis of hydrated compounds and the color change that can occur when water is released and evaporated.
* For the discussion of analysis, heat a sample of CoCl2·6 H2O in a crucible to illustrate how to determine the number of waters of hydration and also discuss the distinctive color change observed during this process.

**Solutions to Study Questions**

2.1 Atoms contain the fundamental particles protons (+1 charge), neutrons (zero charge), and electrons (–1 charge). Protons and neutrons are in the nucleus of an atom. Electrons are the least massive of the three particles.

2.2 Mass number is the sum of the number of protons and number of neutrons for an atom. Atomic mass is the mass of an atom. When the mass is expressed in u, the mass of a proton and of a neutron are both approximately one. Because the mass of electrons is small relative to that of a proton or neutron, the mass number approximates the atomic mass.

2.3 Ratio of diameter of nucleus to diameter of electron cloud is 2 × 10−3 m (2 mm) to 200 m or 1:105. For the diameter of the atom (i.e., the electron cloud) = 1 × 10−10 m (1 × 10−8 cm), the diameter of the nucleus is

1 × 10−10 m/105 = 1 × 10−15 m = 1 × 10−13 cm = 1 fm.

2.4 Each gold atom has a diameter of 2 × 145 pm = 290. pm  
36 cm ·  ·  ·  = 1.2 × 109 Au atoms

2.5 (a)  (b)  (c) 

2.6 (a)  (b)  (c) 

2.7 electrons protons neutrons  
(a) 12 12 12  
(b) 50 50 69  
(c) 90 90 142  
(d) 6 6 7  
(e) 29 29 34  
(f) 83 83 122

2.8 (a) Number of protons = number of electrons = 43; number of neutrons = 56  
(b) Number of protons = number of electrons = 95; number of neutrons = 146

2.9   
The proton is 1834 times more massive than an electron. Dalton’s estimate was off by a factor of about 2.

2.10 Negatively charged electrons in the cathode-ray tube collide with He atoms, splitting the atom into an electron and a He+ cation. The electrons continued to be attracted to the anode while the cations passed through the perforated cathode.

2.11 Alpha particles are positively charged, beta particles are negatively charged, and gamma particles are neutral. Alpha particles have more mass than beta particles.

2.12 Atoms are not solid, hard, or impenetrable. They have mass (an important aspect of Dalton’s hypothesis), and we now know that atoms are in rapid motion at all temperatures above absolute zero (the kinetic-molecular theory).

2.13 16O/12C = 15.995 u/12.000 u = 1.3329

2.14 15.995 u · 1.661 × 10−24 g/u = 2.657 x 10-23 g

2.15  (30 neutrons),  (31 neutrons), and  (33 neutrons)

2.16 Atomic number of Ag is 47; both isotopes have 47 protons and 47 electrons.

107Ag 107 – 47 = 60 neutrons

109Ag 109 – 47 = 62 neutrons

2.17 , protium: one proton, one electron

, deuterium: one proton, one electron, one neutron

, tritium: one proton, one electron, two neutrons

2.18  are isotopes of X

2.19 The atomic weight of thallium is 204.3833. The fact that this weight is closer to 205 than 203 indicates that the 205 isotope is the more abundant.

2.20 Strontium has an atomic weight of 87.62 so 88Sr is the most abundant.

2.21 (6Li mass )(% abundance) + (7Li mass)(% abundance) = atomic weight of Li  
(6.015121 u)(0.0750) + (7.016003 u)(0.9250) = 6.94 u

2.22 (24Mg mass)(% abundance) + (25Mg mass)(% abundance) + (26Mg mass)(% abundance)   
 = atomic weight of Mg  
(23.985 u)(0.7899) + (24.986 u)(0.1000) + (25.983 u)(0.1101)  
 = 24.31 u

2.23 Let *x* represent the abundance of 69Ga and (1 – *x*) represent the abundance of 71Ga.  
69.723 u = (*x*)(68.9257 u) + (1 – *x*)(70.9249 u)  
*x* = 0.6012; 69Ga abundance is 60.12%, 71Ga abundance is 39.88%

2.24 Let *x* represent the abundance of 151Eu and (1 – *x*) represent the abundance of 153Eu.  
151.965 u = (*x*)(150.9197 u) + (1 – *x*)(152.9212 u)  
*x* = 0.4777; 151Eu abundance is 47.77%, 153Eu abundance is 52.23%

2.25 titanium thallium  
symbol Ti Tl  
atomic number 22 81  
atomic weight 47.867 204.3833  
period 4 6  
group 4B 3A  
 metal metal

2.26 silicon tin antimony sulfur selenium  
symbol Si Sn Sb S Se  
atomic number 14 50 51 16 34  
period 3 5 5 3 4  
group 4A 4A 5A 6A 6A  
 metalloid metal metalloid nonmetal nonmetal

2.27 Periods 2 and 3 have 8 elements, Periods 4 and 5 have 18 elements, and Period 6 has 32 elements.

2.28 There are 26 elements in the seventh period, the majority of them are called the Actinides, and many of them are man-made elements.

2.29 (a) C, Cl  
(b) C, Cl, Cs, Ca  
(c) Ce  
(d) Cr, Co, Cd, Cu, Ce, Cf, Cm  
(e) Cm, Cf  
(f) Cl

2.30 There are many correct answers for parts (a) and (d). Possible answers are shown below.  
(a) C, carbon (c) Cl, chlorine  
(b) Rb, rubidium (d) Ne, neon

2.31 Metals: Na, Ni, Np  
Nonmetals: N, Ne

2.32 (a) Bk  
(b) Br  
(c) B  
(d) Ba  
(e) Bi

2.33 Molecular formula for nitric acid: HNO3



Structural formula:

The molecule is planar.

2.34 Molecular formula for asparagine: C4H8N2O3

Structural formula: 

2.35 (a) Mg2+ (b) Zn2+ (c) Ni2+ (d) Ga3+

2.36 (a) Se2– (b) F– (c) Fe2+, Fe3+ (d) N3–

2.37 (a) Ba2+ (e) S2–  
(b) Ti4+ (f) ClO4–  
(c) PO43– (g) Co2+  
(d) HCO3– (h) SO42–

2.38 (a) MnO4– (d) NH4+  
(b) NO2– (e) PO43–  
(c) H2PO4– (f) SO32–

2.39 Potassium loses 1 electron when it becomes a monatomic ion. Argon has the same number of electrons as the K+ ion.

2.40 They both gain two electrons. O2– has the same number of electrons as Ne and S2– has the same number of electrons as Ar.

2.41 Ba2+, Br– BaBr2

2.42 Co3+, F– CoF3

2.43 (a) 2 K+ ions, 1 S2– ion (d) 3 NH4+ ions, 1 PO43– ion  
(b) 1 Co2+ ion, 1 SO42– ion (e) 1 Ca2+ ion, 2 ClO– ions  
(c) 1 K+ ion, 1 MnO4– ion (f) 1 Na+ ion, 1 CH3CO2– ion

2.44 (a) 1 Mg2+ ion, 2 CH3CO2– ions (d) 1 Ti4+ ion, 2 SO42– ions   
(b) 1 Al3+ ion, 3 OH– ions (e) 1 K+ ion, 1 H2PO4– ion  
(c) 1 Cu2+ ion, 1 CO32– ion (f) 1 Ca2+ ion, 1 HPO42– ion

2.45 Co2+: CoO Co3+ Co2O3

2.46 (a) Pt2+: PtCl2 Pt4+: PtCl4  
(b) Pt2+: PtS Pt4+: PtS2

2.47 (a) incorrect, AlCl3 (c) correct  
(b) incorrect, KF (d) correct

2.48 (a) incorrect, CaO (c) incorrect, Fe2O3 or FeO  
(b) correct (d) correct

2.49 (a) potassium sulfide (c) ammonium phosphate  
(b) cobalt(II) sulfate (d) calcium hypochlorite

2.50 (a) calcium acetate (c) aluminum hydroxide  
(b) nickel(II) phosphate (d) potassium dihydrogen phosphate

2.51 (a) (NH4)2CO3 (d) AlPO4  
(b) CaI2 (e) AgCH3CO2  
(c) CuBr2

2.52 (a) Ca(HCO3)2 (d) K2HPO4  
(b) KMnO4 (e) Na2SO3  
(c) Mg(ClO4)2

2.53 Na2CO3 sodium carbonate NaI sodium iodide  
BaCO3 barium carbonate BaI2 barium iodide

2.54 Mg3(PO4)2 magnesium phosphate Mg(NO3)2 magnesium nitrate  
FePO4 iron(III) phosphate Fe(NO3)3 iron(III) nitrate

2.55 The force of attraction is stronger in NaF than in NaI because the distance between ion centers is smaller in NaF (235 pm) than in NaI (322 pm).

2.56 The attractive forces are stronger in CaO because the ion charges are greater (+2/–2 in CaO and +1/–1 in NaCl).

2.57 (a) nitrogen trifluoride (c) boron triiodide  
(b) hydrogen iodide (d) phosphorus pentafluoride

2.58 (a) dinitrogen pentaoxide (c) oxygen difluoride  
(b) tetraphosphorus trisulfide (d) xenon tetrafluoride

2.59 (a) SCl2 (b) N2O5 (c) SiCl4 (d) B2O3

2.60 (a) BrF3 (d) P2F4  
(b) XeF2 (e) C4H10  
(c) N2H4

2.61 (a) 2.5 mol Al ·  = 68 g Al

(b) 1.25 × 10–3 mol Fe ·  = 0.0698 g Fe

(c) 0.015 mol Ca ·  = 0.60 g Ca  
(d) 653 mol Ne ·  = 1.32 × 104 g Ne

2.62 (a) 4.24 mol Au ·  = 835 g Au  
(b) 15.6 mol He ·  = 62.4 g He  
(c) 0.063 mol Pt ·  = 12 g Pt  
(d) 3.63 × 10–4 mol Pu ·  = 0.0888 g Pu

2.63 (a) 127.08 g Cu ·  = 1.9998 mol Cu  
(b) 0.012 g Li ·  = 1.7 × 10–3 mol Li  
(c) 5.0 mg Am ·  ·  = 2.1 × 10–5 mol Am  
(d) 6.75 g Al ·  = 0.250 mol Al

2.64 (a) 16.0 g Na ·  = 0.696 mol Na  
(b) 0.876 g Sn ·  = 7.38 × 10–3 mol Sn  
(c) 0.0034 g Pt ·  = 1.7 × 10–5 mol Pt  
(d) 0.983 g Xe ·  = 7.49 × 10–3 mol Xe

2.65 Helium has the smallest molar mass and will have the largest number of atoms. Iron has the largest molar mass and the smallest number of atoms.  
1.0 g He ·  ·  = 1.5 × 1023 He atoms  
1.0 g Fe ·  ·  = 1.1 × 1022 Fe atoms

2.66 0.10 g K · = 0.0026 mol K

0.10 g Mo · = 0.0010 mol Mo

0.10 g Cr · = 0.0019 mol Cr

0.10 g Al · = 0.0037 mol Al

0.0010 mol Mo < 0.0019 mol Cr < 0.0026 mol K < 0.0037 mol Al

2.67 3.99 g Ca · = 0.0996 mol Ca

1.85 g P · = 0.0597 mol P

4.14 g O · = 0.259 mol O

0.02 g H · = 0.02 mol H

0.02 mol H < 0.0597 mol P < 0.0996 mol Ca < 0.259 mol O

2.68 52 g Ga ·  ·  = 4.5  1023 Ga atoms  
9.5 g Al ·  ·  = 2.1  1023 Al atoms  
112 g As ·  ·  = 9.00  1023 As atoms  
Arsenic has the largest number of atoms in the mixture.

2.69 (a) Fe2O3 159.69 g/mol  
(b) BCl3 117.17 g/mol  
(c) C6H8O6 176.13 g/mol

2.70 (a) Fe(C6H11O7)2 446.14 g/mol  
(b) CH3CH2CH2CH2SH 90.19 g/mol  
(c) C20H24N2O2 324.42 g/mol

2.71 (a) Ni(NO3)2·6H2O 290.79 g/mol  
(b) CuSO4·5H2O 249.69 g/mol

2.72 (a) H2C2O4·2H2O 126.07 g/mol  
(b) MgSO4·7H2O 246.48 g/mol

2.73 (a) 0.0255 mol C3H7OH·  = 1.53 g C3H7OH  
(b) 0.0255 mol C11H16O2 ·  = 4.60 g C11H16O2  
(c) 0.0255 mol C9H8O4 ·  = 4.60 g C9H8O4  
(d) 0.0255 mol (CH3)2CO ·  = 1.48 (CH3)2CO

2.74 (a) 0.123 mol C14H10O4 ·  = 29.8 g C14H10O4  
(b) 0.123 mol C4H8N2O2 ·  = 14.3 g C4H8N2O2  
(c) 0.123 mol C5H10S ·  = 12.6 g C5H10S  
(d) 0.123 mol C12H17NO ·  = 23.5 g C12H17NO

2.75 1.00 kg SO3 ·  ·  = 12.5 mol SO3  
12.5 mol SO3 ·  = 7.52 × 1024 molecules SO3  
7.52 × 1024 molecules SO3 ·  = 7.52 × 1024 S atoms  
7.52 × 1024 molecules SO3 ·  = 2.26 × 1025 O atoms

2.76 0.20 mol (NH4)2SO4 · · = 2.4 × 1023 NH4+ ions

0.20 mol (NH4)2SO4 · · = 1.2 × 1023 SO42- ions

0.20 mol (NH4)2SO4 · · = 2.4 × 1023 N atoms

0.20 mol (NH4)2SO4 · · = 9.6 × 1023 H atoms

0.20 mol (NH4)2SO4 · · = 1.2 × 1023 S atoms

0.20 mol (NH4)2SO4 · · = 4.8 × 1023 O atoms

2.77 Formula: C8H9N1O2

Molar mass: 151.16 g/mol

1 dose = 2 · 500 mg = 1 × 103 mg

1 × 103 mg ·  ·  ·  = 4 × 1021 molecules

2.78 (a) 324 mg C9H8O4 ·  ·  = 1.80 × 10–3 mol C9H8O4  
 1904 mg NaHCO3 ·  ·  = 0.02266 mol NaHCO3  
 1000. mg C6H8O7 ·  ·  = 5.205 × 10–3 mol C6H8O7  
(b) 1.80 × 10–3 mol C9H8O4 ·  = 1.08 × 1021 molecules C9H8O4

2.79 (a)  · 100% = 86.59% Pb  · 100% = 13.40% S  
(b)  · 100% = 81.71% C  · 100% = 18.29% H  
(c)  · 100% = 79.95% C  · 100% = 9.395% H  
  · 100% = 10.65% O

2.80 (a)  · 100% = 57.82% C  · 100% = 6.066% H  
  · 100% = 16.86% N  · 100% = 19.26% O  
(b)  · 100% = 76.86% C  · 100% = 12.90% H  
  · 100% = 10.24% O  
(c)  · 100% = 24.77% Co  · 100% = 29.80% Cl  
  · 100% = 5.084% H  · 100% = 40.35% O

2.81  ·100% = 66.46% Cu  
10.0 g Cu ·  = 15.0 g CuS

2.82  · 100% = 31.55% Ti  
750 g Ti ·  = 2.4 × 103 g FeTiO3

2.83 Empirical formula mass = 59.04 g/mol  = 2  
The molecular formula is (C2H3O2)2, or C4H6O4

2.84 Empirical formula mass = 58.06 g/mol  = 2  
The molecular formula is (C2H4NO)2, or C4H8N2O2

2.85 Empirical formula Molar mass (g/mol) Molecular formula  
(a) CH 26.0 26.0/13.0 = 2 C2H2  
(b) CHO 116.1 116.1/29.0 = 4 C4H4O4  
(c) CH2 112.2 (CH2)8 = C8H16

2.86 Empirical formula Molar mass (g/mol) Molecular formula  
(a) C2H3O3 150.1 150.1/75.0 = 2 C4H6O6  
(b) C3H8 44.1 44.1/44.1 = 1 C3H8  
(c) B2H5 53.3 (B2H5)2 = B4H10

2.87 Assume 100.00 g of compound.  
92.26 g C ·  = 7.681 mol C 7.74 g H ·  = 7.68 mol H  
 The empirical formula is CH  
 = 2 The molecular formula is C2H2

2.88 The compound is 88.5% B and 11.5% H. Assume 100.0 g of compound.  
88.5 g B ·  = 8.19 mol B 11.5 g H ·  = 11.4 mol H  
 The empirical formula is B5H7

2.89 The compound is 89.94% C and 10.06% H. Assume 100.00 g of compound.  
89.94 g C ·  = 7.488 mol C 10.06 g H ·  = 9.981 mol H  
 The empirical formula is C3H4  
 = 3 The molecular formula is C9H12

2.90 Assume 100.00 g of compound.  
57.17 g S ·  = 1.783 mol S 42.83 g C ·  = 3.566 mol C  
 The empirical formula is C2S  
 = 8 The molecular formula is C16S8

2.91 Assume 100.00 g of compound.  
63.15 g C ·  = 5.258 mol C 5.30 g H ·  = 5.26 mol H  
31.55 g O ·  = 1.972 mol O  
 =   =   
The empirical formula is C8H8O3  
The molar mass is equal to the empirical formula mass, so the molecular formula is also C8H8O3

2.92 Assume 100.0 g of compound.  
74.0 g C ·  = 6.16 mol C 8.65 g H ·  = 8.58 mol H  
17.35 g N ·  = 1.239 mol N  
  The empirical formula is C5H7N  
 = 2 The molecular formula is C10H14N2

2.93 0.678 g compound – 0.526 g Xe = 0.152 g F  
0.526 g Xe ·  = 0.00401 mol Xe 0.152 g F ·  = 0.00800 mol F  
 The empirical formula is XeF2

2.94 5.722 g compound – 1.256 g S = 4.466 g F  
1.256 g S ·  = 0.03917 mol S 4.466 g F ·  = 0.2351 mol F  
 The empirical formula is SF6; *x* = 6

2.95 1.394 g MgSO4.7H2O – 0.885 g MgSO4 xH2O = 0.509 g H2O

(0.509 g H2O)(1 mol H2O/18.02 g) = 0.0282 mol H2O lost

(1.394 g MgSO4**.**7H2O)(1 mol MgSO4**.**7H2O /246.48 g) = 0.005656 mol

0.0282 mol/0.005656 mol = 4.99 ~ 5

7 H2O – 5 H2O = 2 H2O left per MgSO4

2.96 3.69 g product – 1.25 g Ge = 2.44 g Cl  
1.25 g Ge ·  = 0.0172 mol Ge 2.44 g Cl ·  = 0.0688 mol Cl  
 The empirical formula is GeCl4

2.97 Symbol 58Ni 33S 20Ne 55Mn  
Number of protons 28 16 10 25  
Number of neutrons 30 17 10 30  
Number of electrons 28 16 10 25  
Name of element nickel sulfur neon manganese

2.98 The atomic weight of potassium is 39.0983 u, so the lighter isotope, 39K is more abundant than 41K.

2.99 *Crossword Puzzle*

|  |  |
| --- | --- |
| S | N |
| B | I |

2.100 (a) Mg is the most abundant main group metal.  
(b) H is the most abundant nonmetal.  
(c) Si is the most abundant metalloid.  
(d) Fe is the most abundant transition element.  
(e) F and Cl are the halogens included ,and of these Cl is the most abundant.

2.101 (a)  ·  = 1.0552  10–22 g/Cu atom  
(b)  = $6.3  10–22/Cu atom

2.102 (d) 3.43 × 10–27 mol S8 is impossible. This amount is less than one molecule of S8.

2.103 (a) Sr, strontium (f) Mg, magnesium  
(b) Zr, zirconium (g) Kr, krypton  
(c) C, carbon (h) S, sulfur  
(d) As, arsenic (i) As, arsenic or Ge, germanium  
(e) I, iodine

2.104 Carbon has three allotropes. Graphite consists of flat sheets of carbon atoms, diamond has carbon atoms attached to four other others in a tetrahedron, and buckminsterfullerene is a 60-atom cage of carbon atoms. Oxygen has two allotropes. Diatomic oxygen consists of molecules containing two oxygen atoms and ozone consists of molecules containing three oxygen atoms.

2.105 (a) One mole of Na has a mass of approximately 23 g, a mole of Si has a mass of 28 g, and a mole of U has a mass of 238 g. A 0.25 mol sample of U therefore represents a greater mass.  
(b) A 0.5 mol sample of Na has a mass of approximately 12.5 g, and 1.2  1022 atoms of Na is approximately 0.02 moles of Na. Therefore 0.50 mol Na represents a greater mass.  
(c) The molar mass of K is approximately 39 g/mol while that of Fe is approximately 56 g/mol. A single atom of Fe has a greater mass than an atom of K, so 10 atoms of Fe represents more mass.

2.106 15 mg ·  ·  = 2.7 × 10–4 mol Fe  
2.7 × 10–4 mol Fe ·  = 1.6 × 1020 atoms Fe

2.107 (a) 3.79 × 1024 atoms Fe ·  ·  = 351 g Fe

(b) 19.921 mol H2 ·  = 40.157 g H2  
(c) 8.576 mol C ·  = 103.0 g C  
(d) 7.4 mol Si ·  = 210 g Si  
(e) 9.221 mol Na ·  = 212.0 g Na  
(f) 4.07 ×1024 atoms Al ·  ·  = 182 g Al  
(g) 9.2 mol Cl2 ·  = 650 g Cl2  
(b) < (c) < (f) < (d) < (e) < (a) < (g)

2.108 0.744 g phosphorus combined with (1.704 g – 0.744 g) = 0.960 g O  
 =   
16.000 u O ·  = 31.0 u P

2.109 (a) Use current values to determine the atomic mass of oxygen if H = 1.0000 u  
 1.0000 u H ·  = 15.873 u O

The value of Avogadro’s number is based on the atomic mass of carbon.  
 1.0000 u H ·  = 11.916 u C  
  = 5.9802 × 1023 particles

(b) 16.0000 u O ·  = 1.00798 u H

16.0000 u O ·  = 12.011 u C

 = 6.0279 × 1023 particles

2.110 68 atoms K ·  ·  = 4.4 × 10–21 g K  
32 atoms Na ·  ·  = 1.2 × 10–21 g Na  
weight % K =  · 100% = 78% K

2.111 (NH4)2CO3 (NH4)2SO4 NiCO3 NiSO4

2.112 A strontium atom has 38 electrons. When an atom of strontium forms an ion, it loses two electrons, forming an ion having the same number of electrons as the noble gas krypton.

2.113 All five compounds contain three chlorine atoms. The compound with the lowest molar mass, (a) BCl3, has the highest weight percent of chlorine.  
 · 100% = 90.77% Cl

2.114 (a) 1.0 g BeCl2 ·  ·  ·  = 2.3 × 1022 atoms  
(b) 1.0 g MgCl2 ·  ·  ·  = 1.9 × 1022 atoms  
(c) 1.0 g CaS ·  ·  ·  = 1.7 × 1022 atoms

(d) 1.0 g SrCO3 ·  ·  ·  = 2.0 × 1022 atoms  
(e) 1.0 g BaSO4 ·  ·  ·  = 1.6 × 1022 atoms  
The 1.0-g sample of (a) BeCl2 has the largest number of atoms.

2.115 3.0 × 1023 molecules represents 0.50 mol of adenine. The molar mass of adenine (C5H5N5) is 135.13 g/mol, so 0.5 mol of adenine has a mass of 67 g. A 40.0-g sample of adenine therefore has less mass than 0.5 mol of adenine.

2.116 (a) BaF2: barium fluoride SiCl4: silicon tetrachloride NiBr2: nickel(II) bromide  
(b) BaF2 and NiBr2 are ionic; SiCl4 is molecular  
(c) 0.50 mol BaF2 ·  = 88 g BaF2  
 0.50 mol SiCl4 ·  = 85 g SiCl4  
 1.0 mol NiBr2 ·  = 219 g NiBr2 1.0 mol NiBr2has the largest mass

2.117 0.050 mL H2O ·  ·  ·  ·  = 1.7 × 1021 molecules H2O

2.118 (a) Molar mass = 305.42 g/mol  
(b) 55 mg C18H27NO3 ·  ·  = 1.8 × 10–4 mol C18H27NO3  
(c)  · 100% = 70.78% C  · 100% = 8.911% H  
  · 100% = 4.587% N  · 100% = 15.72% O  
(d) 55 mg C18H27NO3·  = 39 mg C

2.119 Molar mass = 245.77 g/mol  
 · 100% = 25.86% Cu  
 · 100% = 22.80% N  
 · 100% = 5.742% H  
 · 100% = 13.05% S  
 · 100% = 32.55% O  
10.5 g Cu(NH3)4SO4·H2O ·  = 2.72 g Cu  
10.5 g Cu(NH3)4SO4·H2O ·  = 0.770 g H2O

2.120 (a) Ethylene glycol C2H6O2 Molar mass = 62.07 g/mol  
  · 100% = 38.70% C  · 100% = 51.55% O  
(b) Dihydroxyacetone C3H6O3 Molar mass = 90.08 g/mol  
  · 100% = 40.00% C  · 100% = 53.29% O  
(c) Ascorbic acid C6H8O6 Molar mass = 176.13 g/mol  
  · 100% = 40.91% C  · 100% = 54.51% O  
Ascorbic acid has a larger percentage of carbon and of oxygen.

2.121   
 The empirical formula is C4H6O5.

2.122  · 100% = 36.76% Fe  · 100% = 12.52% Fe  
The tablet containing FeSO4 will deliver more atoms of iron.

2.123 Assume 100.00 g of compound.  
30.70 g Fe ·  = 0.5497 mol Fe 69.30 g CO ·  = 2.474 mol CO  
 The empirical formula is Fe2(CO)9

2.124 (a) C10H15NO Molar mass = 165.23 g/mol  
(b)  · 100% = 72.69% C  
(c) 0.125 g C10H15NO ·  = 7.57 × 10–4 mol C10H15NO  
(d) 7.57 × 10–4 mol C10H15NO ·  = 4.56 × 1020 molecules  
 4.56 × 1020 molecules ·  = 4.56 × 1021 C atoms

2.125 (a) C7H5NO3S  
   
(b) 125 mg C7H5NO3S ·  ·  = 6.82 × 10–4 mol C7H5NO3S  
(c) 125 mg C7H5NO3S ·  = 21.9 mg S

2.126 (a) chlorine trifluoride (f) oxygen difluoride   
(b) nitrogen trichloride (g) potassium iodide, ionic  
(c) strontium sulfate, ionic (h) aluminum sulfide, ionic  
(d) calcium nitrate, ionic (i) phosphorus trichloride  
(e) xenon tetrafluoride (j) potassium phosphate, ionic

2.127 (a) NaOCl, ionic (f) (NH4)2SO3, ionic  
(b) BI3 (g) KH2PO4, ionic  
(c) Al(ClO4)3, ionic (h) S2Cl2   
(d) Ca(CH3CO2)2, ionic (i) ClF3  
(e) KMnO4, ionic (j) PF3

2.128 Cation Anion Name Formula  
NH4+ Br– ammonium bromide NH4Br  
Ba2+ S2– barium sulfide BaS  
Fe2+ Cl– iron(II) chloride FeCl2  
Pb2+ F– lead(II) fluoride PbF2  
Al3+ CO32– aluminum carbonate Al2(CO3)3  
Fe3+ O2– iron(III) oxide Fe2O3

2.129 (a) Assume 100.0 g of compound.  
 14.6 g C ·  = 1.22 mol C 39.0 g O ·  = 2.44 mol O  
 46.3 g F ·  = 2.44 mol F  
    
 The empirical formula is CO2F2. The empirical formula mass is equal to the molar mass, so the molecular formula is also CO2F2.  
(b) Assume 100.00 g of compound.  
 93.71 g C ·  = 7.802 mol C 6.29 g H ·  = 6.24 mol H  
  The empirical formula is C5H4  
  = 2 The molecular formula is C10H8

2.130 Assume 100.00 g of compound.  
22.88 g C ·  = 1.905 mol C 5.76 g H ·  = 5.71 mol H  
71.36 g As ·  = 0.9525 mol As  
   
The empirical formula is C2H6As  
 = 2 The molecular formula is C4H12As2

2.131 Assume 100.00 g of compound.  
58.77 g C ·  = 4.893 mol C 13.81 g H ·  = 13.70 mol H  
27.40 g N ·  = 1.956 mol N  
   
The empirical formula is C5H14N2. The empirical formula mass is equal to the molecular mass, so the molecular formula is also C5H14N2.

2.132 0.364 g Ni(CO)x – 0.125 g Ni = 0.239 g CO  
0.239 g CO ·  = 0.00853 mol CO 0.125 g Ni ·  = 0.00213 mol Ni  
 The compound formula is Ni(CO)4 (*x* = 4)

2.133 Assume 100.0 g of compound.  
49.5 g C ·  = 4.12 mol C 3.2 g H ·  = 3.2 mol H  
22.0 g O ·  = 1.38 mol O 25.2 g Mn ·  = 0.459 mol Mn  
   
 The empirical formula is C9H7MnO3

2.134  · 100% = 19.97% P  
15.0 kg P ·  = 75.1 kg Ca3(PO4)2

2.135  · 100% = 68.42% Cr  
850 kg Cr ·  = 1200 kg Cr2O3

2.136  · 100% = 71.69% Sb  
1.00 kg ore ·  ·  ·  = 148 g Sb2S3

2.137 1.246 g I*x*Cl*y* – 0.678 g I = 0.568 g Cl  
0.678 g I ·  = 0.00534 mol I 0.568 g Cl ·  = 0.0160 mol Cl  
 The empirical formula is ICl3  
 = 2 The molecular formula is I2Cl6

2.138 2.04 g V ·  = 0.0400 mol V 1.93 g S ·  = 0.0602 mol S  
 The empirical formula is V2S3

2.139 15.8 kg FeS2 ·  = 7.35 kg Fe

2.140 (a) True. 0.500 mol C8H18 ·  = 57.1 g C8H18  
(b) True.  · 100% = 84.1% C  
(c) True.  
(d) False. 57.1 g C8H18 ·  = 9.07 g H

2.141 (d) Na2MoO4

2.142   
Molar mass MCl4 = 189.7 g  
Atomic weight M = 189.7 g MCl4 – (4)(35.453) g Cl = 47.9 g  
M is Ti, titanium

2.143 2 tablets ·  ·  ·  = 5.52 × 10–4 mol C21H15Bi3O12  
5.52 × 10–4 mol C21H15Bi3O12 ·  ·  = 0.346 g Bi

2.144  Molar mass MO2 = 211 g  
Atomic weight M = 211 g MO2 – (2)(16.00) g O = 179 g M is Hf, hafnium

2.145 Molar mass of compound =  = 154 g/mol  
154 g/mol = (molar mass of E) + [4 × (molar mass of Cl)] = ME + 4(35.45 g/mol)  
ME = 12  
E is C, carbon.

2.146  = 106 g/mol A2Z3  = 62 g/mol AZ2  
For AZ2: (atomic mass A) + (2)(atomic mass Z) = 62  
For A2Z3: (2)(atomic mass A) + (3)(atomic mass Z) = 106  
 (2)[62 – (2)(atomic mass Z)] + (3)(atomic mass Z) = 106  
 atomic mass Z = 18 g/mol  
 atomic mass A = 26 g/mol

2.147  · 100% = 0.105 % Br  
molar mass Br3C6H3(C8H8)*x* = 2.28 × 105 g/mol  
2.28 × 105 g/mol = (3)(79.904) g Br + (6)(12.011) g C + (3)(1.0079) g H + (*x*)(104.15) g C8H8  
*x* = 2.19 × 103

2.148  · 100% = 0.335% Fe  
molar mass hemoglobin = 1.67 × 104 g/mol  
 · 100% = 0.335% Fe  
molar mass hemoglobin = 6.67 × 104 g/mol

2.149 (a) mass of nucleus = 1.06 × 10–22 g (electron mass is negligible)  
 nuclear radius = 4.8 × 10–6 nm ·  ·  = 4.8 × 10–13 cm  
 volume of nucleus = (4/3)()(4.8 × 10–13 cm)3 = 4.6 × 10–37 cm3  
 density of nucleus =  = 2.3 × 1014 g/cm3  
(b) atomic radius = 0.125 nm ·  ·  = 1.25 × 10–8 cm  
 volume of Zn atom = (4/3)()(1.25 × 10–8 cm)3 = 8.18 × 10–24 cm3  
 volume of space occupied by electrons = 8.18 × 10–24 cm3 – 4.6 × 10–37 cm3  
 = 8.18 × 10–24 cm3  
 density of space occupied by electrons =  = 3.34 × 10–3 g/cm3  
(c) The nucleus is much more dense than the space occupied by the electrons.

2.150 (a) Volume of cube = (1.000 cm)3 = 1.000 cm3  
 1.000 cm3 Pb ·  ·  ·  = 3.299 × 1022 atoms Pb

(b) Volume of one lead atom =  = 1.819 × 10–23 cm3  
 1.819 × 10–23 cm3 = (4/3)()(Pb radius)3  
 Pb radius = 1.631 × 10–8 cm

2.151 (a) volume = (0.0550 cm)(1.25 cm)2 = 0.0859 cm3 Ni  
 0.0859 cm3 Ni ·  = 0.765 g Ni (0.765 g Ni)(1 mol Ni/58.69 g Ni) = 0.0130 mol Ni  
(b) 1.261 g compound – 0.765 g Ni = 0.496 g F  
 0.765 g Ni ·  = 0.0130 mol Ni 0.496 g F ·  = 0.0261 mol F  
  The empirical formula is NiF2  
(c) NiF2, nickel(II) fluoride

2.152 (a) 0.199 g U*x*O*y* – 0.169 g U = 0.030 g O  
 0.169 g U ·  = 7.10 × 10–4 mol U  
 0.030 g O ·  = 1.9 × 10–3 mol O  
   
 The empirical formula is U3O8, a mixture of uranium(IV) oxide and uranium(VI) oxide.  
 7.10 × 10–4 mol U ·  = 2.37 × 10–4 mol U3O8

(b) The atomic weight of U is 238.029 u, implying that the isotope 238U is the most abundant.

(c) 0.865 g – 0.679 g = 0.186 g H2O lost upon heating  
 0.186 g H2O ·  = 0.0103 mol H2O  
 0.679 g UO2(NO3)2 ·  = 0.00172 mol UO2(NO3)2  
   
 The formula of the hydrated compound is UO2(NO3)2 ·6 H2O

2.153 0.125 mol Na ·  ·  = 3.0 cm3  
Edge =  = 1.4 cm

2.154 Assume 100.0 g of sample.  
54.0 g C ·  = 4.50 mol C 6.00 g H ·  = 5.95 mol H  
40.0 g O ·  = 2.50 mol O  
   
Answer (d) C9H12O5 is correct. The other students apparently did not correctly calculate the number of moles of material in 100.0 g or they improperly calculated the ratio of those moles in determining their empirical formula.

2.155 (a) The most abundant isotopes of C, H, and Cl are 12C, 1H, and 35Cl. The peak at 50 *m/z* is due to ions with the makeup 12C1H335Cl+ while the peak at 52 m/z is due to 12C1H337Cl+ ions. The peak at 52 *m/z* is about 1/3 the height of the 50 m/z peak because the abundance of 37Cl is about 1/3 that of 35Cl.

(b) The species at 51 *m/z* are 13C1H335Cl+ and 12C1H22H135Cl+.

2.156 (a) *m/Z* 158 79Br2

*m/Z* 160 79Br81Br

*m/Z* 162 81Br2

(b) The abundances are close enough to assume an equal abundance of 79Br and 81Br. Two atoms from the two isotopes can be combined in four different manners to form Br2: 79Br2, 79Br81Br, 81Br79Br, and 81Br2. Thus, the peak at *m/Z* 160 should have twice the intensity of the peaks at *m/Z* 158 and 162.

2.157 1.687 g hydrated compound – 0.824 g MgSO4 = 0.863 g H2O  
0.863 g H2O ·  = 0.0479 mol H2O  
0.824 g MgSO4 ·  = 0.00684 mol MgSO4  
 There are 7 water molecules per formula unit of MgSO4

2.158 4.74 g hydrated compound – 2.16 g H2O = 2.58 g KAl(SO4)2  
2.16 g H2O ·  = 0.120 mol H2O  
2.58 g KAl(SO4)2 ·  = 0.00999 mol KAl(SO4)2  
  
There are 12 water molecules per formula unit of KAl(SO4)2; *x* = 12

2.159 1.056 g Sn total – 0.601 g Sn remaining = 0.455 g Sn consumed

0.455 g Sn . = 0.00383 mol Sn

1.947 g I consumed . = 0.01534 mol I

0.01534 mol I/0.00383 mol Sn = 4.01 mol I/mol Sn

Formula is SnI4.

2.160 Assume 100.0 g of sample.  
54.0 g C ·  = 4.50 mol C 6.00 g H ·  = 5.95 mol H  
40.0 g O ·  = 2.50 mol O  
   
Answer (d) C9H12O5 is correct. The other students apparently did not correctly calculate the number of moles of material in 100.0 g or they improperly calculated the ratio of those moles in determining their empirical formula.

2.161 0.832 g hydrated sample – 0.739 g heated sample = 0.093 g H2O

0.093 g H2O ·  = 0.0052 mol H2O  
0.739 g CaCl2 ·  = 0.00666 mol CaCl2  
  
The students should (c) heat the crucible again and then reweigh it.

2.162 14.710 g crucible & Sn – 13.457 g crucible = 1.253 g Sn

1.253 g Sn . = 0.01056 mol Sn

15.048 g crucible & Sn & O – 14.710 g crucicble & Sn = 0.338 g O

0.338 g O . = 0.0211 mol O

0.0211 mol O/0.01056 mol Sn = 2 mol O/1 mol Sn

Formula is SnO2.

2.163 (b) the molar mass of iron, (c) Avogadro’s number, and (d) the density of iron are needed  
1.00 cm3 ·  ·  ·  = 8.49 × 1022 atoms Fe

2.164 Element abundance generally decreases with increasing atomic number (with exceptions at Li–B and Sc–Fe). Elements with an even atomic number appear to be slightly more abundant than those with an odd atomic number.

2.165 (a) Barium would be even more reactive than calcium, so a more vigorous evolution of hydrogen would occur (it might even ignite).  
(b) Mg, Ca, and Ba are in periods 3, 4, and 6, respectively. Reactivity increases on going down a group in the periodic table.

2.166 One possible method involves the following steps: (1) weigh a representative sample of jelly beans (about 10) in order to determine the average mass of a jelly bean; (2) weight the jelly beans in the jar (subtract the mass of the empty jar from the mass of the jar filled with jelly beans; (3) use the average mass per jelly bean and the total mass of the jelly beans in the jar to determine the approximate number of jelly beans in the jar.

**SOLUTIONS TO APPLYING CHEMICAL PRINCIPLES: ARGON – AN AMAZING DISCOVERY**

1. 0.20389 g · (1 L/1.25718 g) = 0.16218 L = 162.18 mL = 162.18 cm3

2. (0.2096)(1.42952 g/L) + (0.7811)(1.25092 g/L) + (0.00930)X = 1.000(1.29327 g/L)

X = 1.78 g/L

3. Argon *M* = 39.948 u

100 % – 0.337 % – 0.063 % = 99.600 %

(0.00337)(35.967545 u) + (0.00063)(37.96732 u) +(0.99600)X = 39.948 u

X = 39.963 u

4. 4.0 m · 5.0 m · 2.4 m · (1 L/1.00 × 10-3 m3) = 4.8 × 104 L

4.8 × 104 L · 1.78 g/L · 1 mol/39.948 g · 6.022 × 1023 atoms/mol = 1.3 × 1027 atoms