# Chapter 2: Atoms

<u>QC 2.1</u> (a) $NaClO_3$ (b) $AlF_3$

<u>QC 2.2</u> (a) The mass number is 15 + 16 = 31.
(b) The mass number is 86 + 136 = 222.

<u>QC 2.3</u> (a) The element has 15 protons, making it phosphorus (P); its symbol is $^{31}_{15}\mathrm{P}$.
(b) The element has 86 protons, making it radon (Rn); its symbol is $^{222}_{86}\mathrm{Rn}$.

<u>QC 2.4</u> (a) The atomic number of mercury (Hg) is 80; that of lead (Pb) is 82.
(b) An atom of Hg has 80 protons; an atom of Pb has 82 protons.
(c) The mass number of this isotope of Hg is 80 + 120 = 200; the mass number for this isotope of Pb is 82 + 120 = 202.
(d) The symbols of these isotopes are $^{200}_{80}\mathrm{Hg}$ and $^{202}_{82}\mathrm{Pb}$.

<u>QC 2.5</u> The atomic number of iodine (I) is 53. The number of neutrons in each isotope is 125 - 53 = 72 for iodine-125 and 131 - 53 = 78 for iodine-131. The symbols for these two isotopes are $^{125}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$.

<u>QC 2.6</u> The atomic weight is 6.941 amu, which is nearer to 7 amu than 6 amu. Therefore, lithium-7 is the more abundant isotope. The relative abundances for these two isotopes are 92.50 percent for lithium-7 and 7.50 percent for lithium-6.

<u>QC 2.7</u> This element has 13 electrons and, therefore, 13 protons. The element with atomic number 13 is Aluminum (Al).

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<u>2.2</u> (b), (c), (d), (f), (g), (h), and (k): True
(a) False: matter is divided into pure substances and mixtures.
(e) False: mixtures can be separated into their component pure substances.
(i) False: technetium, promethium, and all of the elements beyond uranium are artificial.
(j) False: H, O, C, N, Ca, and P are the six most important elements in the human body.
(l) False: the combining ratio is based on a ratio of atoms, not a ratio of masses.

<u>2.4</u> (a) Oxygen (b) Lead (c) Calcium (d) Sodium (e) Carbon (f) Titanium
(g) Sulfur (h) Iron (i) Hydrogen (j) Potassium (k) Silver (l) Gold

<u>2.6</u> Given here is the element, its symbol, and its atomic number:
(a) Americium (Am, 95) (b) Berkelium (Bk, 97) (c) Californium (Cf, 98)
(d) Dubnium (Db, 105) (e) Europium (Eu, 63) (f) Francium (Fr, 87)
(g) Gallium (Ga, 31) (h) Germanium (Ge, 32) (i) Hafnium (Hf, 72)
(j) Hassium (Hs, 108) (k) Holmium (Ho, 67) (l) Lutetium (Lu, 71)
(m) Magnesium (Mg, 12) (n) Polonium (Po, 84) (o) Rhenium Re, 75)
(p) Ruthenium (Ru, 44) (q) Scandium (Sc, 21) (r) Strontium (Sr, 38)
(s) Ytterbium (Yb, 70), Terbium (Tb, 65), and Yttrium (Y, 39)
(t) Thulium (Tm, 69)

<u>2.8</u> (a) $K_2O$ (b) $Na_3PO_4$ (c) $LiNO_3$

<u>2.10</u> (a) The law of conservation of mass states that matter can be neither created nor destroyed. Dalton's theory explains this because if all matter is made up of indestructible atoms, then any chemical reaction just changes the attachments between atoms and does not destroy the atoms themselves.
(b) The law of constant composition states that any compound is always made up of elements in the same proportion by mass. Dalton's theory explains this because molecules consist of tightly bound groups of atoms, each of which has a particular mass. Therefore, each element in a compound always constitutes a fixed proportion of the total mass.

<u>2.12</u> No. CO and $CO_2$ are different compounds, and each obeys the law of constant composition for that particular compound.

<u>2.14</u> (b), (c), (e), (f), (g), (h), (k), (m), (o), (p), (q), and (s): True
(a) False: electrons and protons have equal, but opposite charges. Electrons are much lighter in mass than protons.
(d) False: 1 amu = $1.6605 \times 10^{-24}$ grams.
(i) False: opposite charges attract each other.
(j) False: the size of the atom includes the space occupied by the electrons. The nucleus is a small fraction of the size of the atom.
(l) False: the mass number is the number of protons and neutrons.
(n) False: $^{1}H$ has no neutrons, $^{2}H$ has one neutron, and $^{3}H$ has two neutrons.
(r) False: atomic weights are weighted averages of the known isotopes and their abundances.
(t) False: density is mass/volume.

<u>2.16</u> The statement is true. The element is determined by the number of protons (the atomic number).

2.18 (a) The element with 22 protons is titanium (Ti).
(b) The element with 76 protons is osmium (Os).
(c) The element with 34 protons is selenium (Se).
(d) The element with 94 protons is plutonium (Pu).

2.20 Each would still be the same element because the number of protons has not changed.
(a) The element is scandium (Sc), and its symbol is $^{47}_{21}Sc$.
(b) The element is titanium (Ti), and its symbol is $^{50}_{22}Ti$.
(c) The element is silver (Ag), and its symbol is $^{109}_{47}Ag$.
(d) The element is thorium (Th) and its symbol is $^{248}_{90}Th$.
(e) The element is argon (Ar) and its symbol is $^{38}_{18}Ar$.

2.22 Radon (Rn) has an atomic number of 86, so each isotope has 86 protons. The number of neutrons is mass number - atomic number.
(a) Radon-210 has 210 - 86 = 124 neutrons
(b) Radon-218 has 218 - 86 = 132 neutrons
(c) Radon-222 has 222 - 86 = 136 neutrons

2.24 Two more neutrons: tin-120
Three more neutrons: tin-121
Six more neutrons: tin-124

2.26 (a) An ion is an atom or group of bonded atoms with an unequal number of protons and electrons.
(b) Isotopes are atoms with the same number of protons in their nuclei but a different number of neutrons.

2.28 Rounded to four significant figures, the calculated value is 12.01 amu. The value given in the Periodic Table is 12.011 amu.

$$\left(\frac{98.90}{100} \times 12.000 \text{ amu}\right) + \left(\frac{1.10}{100} \times 13.003 \text{ amu}\right) = 12.01 \text{ amu}$$

2.30 Carbon-11 has 6 protons, 6 electrons, and 5 neutrons.

2.32 Americium-241 (Am) has atomic number 95. This isotope has 95 protons, 95 electrons and 241 - 95 = 146 neutrons.

<u>2.34</u> (a), (f), (g), (h), and (i): True
(b) False: main group elements go from groups 1A through 8A
(c) False: very roughly, the metalloids exist in a diagonal, starting in the lower right corner, moving up to upper middle of the Periodic Table. Nonmetals exist above the diagonal, metals below it.
(d) False: there are more metals than nonmetals
(e) False: horizontal rows are called periods.

<u>2.36</u> (a) Groups 2A(2), 3B (3), 4B (4), 5B (5), 6B (6), 7B (7), 8B (8,9, and 10), 1B (11), and 2B (12) contain only metals. Note that Group 1A contains one nonmetal, hydrogen.
(b) No group contains only metalloids.
(c) Only Groups 7A (17) and 8A (18) contain only nonmetals.

<u>2.38</u> In the Periodic Table, elements of the same group should have similar properties: As, N, and P; I and F; Ne and He; Mg, Ca, and Ba; K and Li.

<u>2.40</u> (a) aluminum > silicon (b) arsenic > phosphorus
(c) gallium > germanium (d) gallium > aluminum

<u>2.42</u> (a), (b), (c), (e), (g), (h), (j), (k), (l), (m), (n), (q), (r), and (s): True
(d) False: principal energy level 1 contains a maximum of two electrons, the principal energy level 2 contains a maximum of eight electrons, the principal energy level 3 contains a maximum of 18 electrons, and the principal energy level 4 contains a maximum of 32 electrons.
(f) False: a 2*s* electron is easier to remove than a 1*s* electron because it is further away from the influence of the positively charged nucleus.
(i) False: The three 2*p* orbitals are arranged perpendicular to each other.
(o) False: paired electrons have spins in the opposite direction.
(p) False: each box represents an orbital and each orbital can accommodate two electrons. When an orbital is completely filled, the electrons must be paired with spins in the opposite direction.
(t) False: group 6A elements have two unpaired electrons.

<u>2.44</u> The group number indicates the number of electrons in the valence shell of the element.

<u>2.46</u> (a) Li(3): $1s^22s^1$ (b) Ne(10): $1s^22s^22p^6$ (c) Be(4): $1s^22s^2$
(d) C(6): $1s^22s^22p^2$ (e) Mg(12): $1s^22s^22p^63s^2$

<u>2.48</u> (a) He(2): $1s^2$ (b) Na(11): $1s^22s^22p^63s^1$ (c) Cl(17): $1s^22s^22p^63s^23p^5$
(d) P(15): $1s^22s^22p^63s^23p^3$ (e) H(1): $1s^1$

<u>2.50</u> In (a), (b), and (c); the outer-shell electron configurations are the same. The only difference is the principal energy level of the valence shell being filled.

2.52 The element X might be in Group 2A, all of which have two valence electrons. It might also be helium.

2.54 (a), (b), (c), (f), and (h): True
(d) False: helium is a group 8A element and has two valence electrons.
(e) False: the period number has nothing to do with the number of elements.
(g) False: period 3 has eight elements.

2.56 (a), (b), (c), (d), and (f): True
(e) False: ionization energy decreases going from top to bottom within a column of the Periodic Table.

2.58 (a) The additional electron in the valence shell exceeds the positive charge in the nucleus causing the electrons in the valence shell to be held less tightly, thus increasing the atomic radius. Also, the additional electron in the valence shell introduces new repulsions causing the electron cloud to expand.
(b) With the loss of a valence electron, the positive charge in the nucleus exceeds the collective negative charge of the electrons, causing the valence electrons to be held more tightly, thus decreasing the atomic radius. Also, one less electron in the valence shell reduces the electron-electron repulsions causing the electron cloud to contract.

2.60 Ionization energies generally increase going from left to right in a period of the Periodic Table due to the increasing positive charge in the nucleus. As the nucleus becomes more positively charge within a period, the valence electrons become more difficult to remove in an ionization.

2.62 Sulfur and iron are essential components of proteins, and calcium is a major component of bones and teeth.

2.64 Calcium is an essential element in human bones and teeth. Because strontium behaves chemically much like calcium, strontium-90 gets into our bones and teeth and gives off radioactivity for many years directly into our bodies.

2.66 Copper can be made harder by hammering it.

2.68 (a) Metals (b) Nonmetals (c) Metals
(d) Nonmetals (e) Metals (f) Metals

2.70 The atomic radius decreases going from left to right across a period in the Periodic Table. Atomic radius increases going down a group (column) in the Periodic Table.
(a) Radium (Ra) (d) Neon (Ne)
(b) Beryllium (Be) (e) Fluorine (F)
(c) Lithium (Li) (f) Astatine (At)

2.72 (a) Phosporous-32 has 15 protons, 15 electrons, and 32 - 15 = 17 neutrons.
(b) Molybdenum-98 has 42 protons, 42 electrons, and 98 - 42 = 56 neutrons.
(c) Calcium-44 has 20 protons, 20 electrons, and 44 - 20 = 24 neutrons.
(d) Hydrogen-3 has 1 proton, 1 electron, and 3 - 1 = 2 neutrons.
(e) Gadolinium-158 has 64 protons, 64 electrons, and 158 - 64 = 94 neutrons.
(f) Bismuth-212 has 83 protons, 83 electrons, and 212 - 83 = 129 neutrons.

2.74 For elements with atomic numbers less than that of iron (Fe), the number of neutrons is close to the number of protons. Elements with atomic numbers greater than that of iron have more neutrons than protons. Therefore, heavy elements typically have more neutrons than protons.

2.76 Rounded to four significant figures, the atomic weight of naturally occurring boron is 10.81 amu. The value given in the Periodic Table is 10.811 amu.

$$\left(\frac{19.9}{100} \times 10.013 \text{ amu}\right) + \left(\frac{80.1}{100} \times 11.009 \text{ amu}\right) = 10.8 \text{ amu}$$

2.78 It would take 6.0 x $10^{21}$ protons to equal the mass of a grain of salt.

$$\frac{1.0 \text{ x } 10^{-2} \text{ g NaCl}}{1.67 \text{ x } 10^{-24} \text{ g/ proton}} = 6.0 \text{ x } 10^{21} \text{ protons}$$

2.80 The atomic number of this element is 54, which means that it is xenon (Xe). This isotope of xenon has 54 protons, 54 electrons, and 131 - 54 = 77 neutrons.

2.82 (a) Ionization energy generally decreases down a column in the Periodic Table, so the ionization energy of Tennessine should be less than that of At(85).
(b) Ionization energy generally increases from left to right across a row in the Periodic Table, so ionization energy of Tennessine should be greater than Ra(88).

2.84 (a) The first electron is removed from the 2*s* orbital. The removal of each subsequent electron requires more energy because, after the first electron is removed, each subsequent electron is removed from a positive ion, which strongly attracts the remaining electrons. The second ionization energy is especially large because the electron is removed from the filled first principal energy level, meaning that it is removed from an ion that has the same electron configuration as helium.
(b) $Li^+$ ion has a smaller radius than Li because with the loss of a valence electron from Li, the positive charge in the nucleus exceeds the collective negative charge of the electrons, causing the valence electrons to be held more tightly, thus decreasing the atomic radius. Also, one less electron in the valence shell of $Li^+$ reduces the electron-electron repulsions causing the electron cloud to contract.

2.86 Increasing size: C < B < Al < Na
There are relatively small decreases in atomic radii going from left to right in the Periodic Table due to the increasingly stronger pull on the electrons because of the additional protons, therefore, the size of the atomic radii can be compared as C < B and Al < Na. Going to a higher numbered period in the Periodic Table results in a much larger increase in atomic radii, therefore, both Na and Al are larger than C and B.

2.88 Going down Group 3A, we have boron, aluminum, gallium, indium, and thallium. The electron configuration of each 3A element tells us that the valence shell *s* orbitals are completely filled and that the valence shell *p* orbital has one electron.

2.90 The $Ca^{3+}$ ion is not found in chemical compounds because calcium only needs to lose two electrons to achieve a stable noble gas electronic configuration. Losing three electrons brings the electronic configuration away from a stable noble gas electronic configuration.

2.92 If the bromine is all used up, it is assumed that it is the limiting reagent. The reaction of magnesium and bromine is as follows:

$$\text{Mg} + \text{Br}_2 \rightarrow \text{MgBr}_2$$

$$\text{Mg reacted} = \frac{1.80\ \cancel{\text{g Br}_2}}{}\left(\frac{1\ \cancel{\text{mol Br}_2}}{159.8\ \cancel{\text{g Br}_2}}\right)\left(\frac{1\ \cancel{\text{mol Mg}}}{1\ \cancel{\text{mol Br}_2}}\right)\left(\frac{24.305\ \text{g Mg}}{1\ \cancel{\text{mol Mg}}}\right) = 0.274\ \text{g}$$

$$\text{Mg remaining} = 7.12\ \text{g (Mg initial mass)} - 0.274\ \text{g (Mg reacted)} = 6.85\ \text{g}$$

2.94 Answers in bold. The mass numbers derived reflect the most abundant isotope.

| Symbol | Atomic number | Atomic weight | Mass number | # of protons | # of neutrons | # of electrons |
|---|---|---|---|---|---|---|
| H | **1** | **1.0079** | **1** | **1** | **0** | **1** |
| Li | **3** | **6.941** | **7** | **3** | **4** | 3 |
| Al | **13** | **26.9815** | **27** | **13** | **14** | **13** |
| **Fe** | 26 | **55.845** | 58 | **26** | **32** | **26** |
| **Pt** | **78** | **195.084** | **195** | 78 | **117** | **78** |
| **Ca** | **20** | **40.078** | **37** | **20** | 17 | 20 |
| **S** | 16 | **32.066** | **32** | **16** | **16** | **16** |

2.96 $$0.4818\left({}^{109}\text{Ag atomic mass}\right) + 0.5182(106.905\ \text{amu}) = 107.868\ \text{amu}$$

$${}^{109}\text{Ag atomic mass} = \frac{52.47\ \text{amu}}{0.4818}$$

$${}^{109}\text{Ag atomic mass} = 108.9\ \text{amu}$$

2.98 If $^{30}Si$ has an isotopic abundance of 3.09%, then $^{28}Si$ + $^{29}Si$ = 96.91% of the mix. Therefore, if $^{28}Si$ = x and $^{29}Si$ = y, then (x + y) = 0.9691 and y = (0.9691 – x ).

(1) 27.977(x) amu + 28.086 (y) amu + 29.974 ´ (0.0309) amu = 28.086 amu

(2) replace y with (0.9691 – x) and then solve for x

(3) 27.977(x) amu + 28.086 (0.9691 – x) amu + 29.974 ´ (0.0309) amu = 28.086 amu

x = 0.9217

The isotopic abundance is: $^{28}Si$ = 92.17%, $^{29}Si$ = 4.74%, and $^{30}Si$ = 3.09% (given)

2.100 (a) Ar (b) Al (c) Si (d) Cl (e) Mg (f) P (g) Ar (h) S