

Solutions manual

to accompany

Chemistry 3rd edition

by Blackman, Bottle, Schmid,
Mocerino & Wille

Prepared by
Allan Blackman

WILEY

© John Wiley & Sons Australia, Ltd 2016

Chapter 1: The atom

Practice exercises

- 1.1 The first sample has a ratio of:

$$\frac{1.00 \text{ g Ti}}{0.668 \text{ g O}}$$

The law of definite proportions tells us that the second sample must have the same ratio of Ti to O:

$$\frac{1.00 \text{ g Ti}}{0.668 \text{ g O}} = \frac{x}{2.50 \text{ g O}}$$

Rearranging the equation to solve for x gives:

$$\begin{aligned} x &= \frac{(1.00 \text{ g Ti})(2.50 \text{ g O})}{0.668 \text{ g O}} \\ &= 3.74 \text{ g Ti} \end{aligned}$$

- 1.2 (a) number of protons = 71; number of neutrons = $(177 - 71) = 106$
(b) number of protons = 54; number of neutrons = $(133 - 54) = 79$
(c) number of protons = 77; number of neutrons = $(192 - 77) = 115$
- 1.3 Average atomic mass of Ne:
 $= (0.9048 \times 19.9924 \text{ u}) + (0.0027 \times 20.9938 \text{ u}) + (0.0925 \times 21.9914 \text{ u})$
 $= 20.18 \text{ u}$

Review questions

- 1.1 An atom is a chemical species comprising a central positively charged nucleus surrounded by one or more negatively charged electrons.
- A covalent bond is a chemical bond which involves the sharing of electrons between neighbouring atoms.
- An ion is a charged chemical species; the charge may be either positive or negative.
- A cation is a positively charged chemical species.
- An anion is a negatively charged chemical species.
- An element is a chemical species comprised of only a single type of atom.
- A compound is a chemical species comprised of two or more elements in a definite and unchanging proportion.
- A reactant is a chemical species which is transformed in a chemical reaction.
- A chemical reaction is a process whereby one or more chemical species is/are transformed into different chemical species. This generally involves the making and/or breaking of chemical bonds.
- A product is the species formed in a chemical reaction.
- 1.2 The first law of chemical combination is the law of conservation of mass: no detectable gain or loss of mass occurs in chemical reactions.
- The second law is the law of definite proportions: in a given chemical compound, the elements are always combined in the same proportions by mass.
- The third law is the law of multiple proportions: whenever two elements form more than one compound, the different masses of one element that combine with the same mass of the other element are in the ratio of small whole numbers.
- 1.3 The law of conservation of mass says that mass is conserved in chemical reactions. This being the case, then there must be the same mass on either side of the arrow in a chemical equation, and hence the same number of each type of atom on either side of the arrow.
- 1.4 The law of definite proportions. Chemical elements always combine in a definite fixed proportion by mass to form chemical compounds.
- 1.5 The ratio of small whole numbers, mentioned in the law of multiple proportions, is consistent with the existence of discrete entities that combine with each other in integer multiples. These discrete entities are atoms.
- 1.6 $^{12}_6\text{C}$. This isotope has a mass of 12 u (exactly) by definition.

- 1.7 They passed through undeflected because most of the atom is empty space and they did not encounter any particles that could deflect them. The force that did lead to some deflections was electrostatic; both the atomic nucleus and alpha particles are positively charged, and will repel each other.
- 1.8 Nearly all of the mass is located in the nucleus, because this is the portion of the atom where the proton(s) and the neutron(s), the heaviest constituent particles of the atom, are located.
- 1.9 Electrons are much lighter (about 10 000 times) than both protons and neutrons. Therefore, their contribution to the overall mass of an atom can be neglected for all but the most precise of measurements.
- 1.10 The atomic number is equal to the number of protons in the nucleus of the atom, and the mass number is the sum of the neutrons and the protons.
- 1.11 Isotopes are atoms of an element having identical numbers of protons (and therefore the same atomic numbers) but differing numbers of neutrons (and therefore different mass numbers). Their chemical behaviour is similar because the chemistry of an atom is determined primarily by its atomic number. For example, the isotopes protium, deuterium and tritium all undergo reactions typical of hydrogen, despite the fact they have different mass numbers.
- 1.12 (a) A is the mass number (number of protons + number of neutrons).
(b) Z is the atomic number (number of protons).
- 1.13 (a) $^{107}_{47}\text{Ag}$
(b) $^{181}_{73}\text{Ta}$
(c) $^{162}_{66}\text{Dy}$
(d) $^{14}_8\text{O}$
- 1.14 (a) Cl
(b) S
(c) Fe
(d) Ag
(e) Na
(f) P
(g) I
(h) Cu
(i) Hg
(j) Ca
- 1.15 (a) lithium
(b) gold
(c) uranium
(d) arsenic
(e) cobalt
(f) bromine
(g) platinum
(h) boron
(i) neon
(j) beryllium

- 1.16 Mendeleev constructed his periodic table by arranging the elements in order of increasing atomic weight and grouping the elements by their recurring properties. The modern periodic table is arranged in order of increasing number of protons (increasing atomic number).
- 1.17 False. A period in the periodic table is a horizontal row of elements. It is the elements in a group, one of the vertical columns of the periodic table, that behave chemically similarly.
- 1.18 Not all of the elements had yet been discovered; therefore Mendeleev left spaces for the ones that he predicted would eventually be discovered because he grouped elements with similar chemical properties together.
- 1.19 The atomic number — the number of protons in the nucleus (and the number of electrons in the neutral atom) — is related to the chemistry of an element. The periodic table is based on atomic numbers. The mass numbers, which vary with the number of neutrons in the atom, do not affect the chemistry of the elements as much as the number of protons.
- 1.20 Strontium and calcium are in the same group of the periodic table, so they are expected to have similar chemical properties. Strontium should therefore form compounds that are similar to those of calcium, including the types of compounds found in bone.
- 1.21 Palladium and platinum are in the same group of the periodic table as nickel (group 10), so they might well be expected to occur together in nature because of their similar chemical properties and tendencies to form similar compounds.
- 1.22 Cadmium is in the same periodic table group as zinc, but silver is not. Therefore cadmium is expected to have properties similar to those of zinc, and should therefore be found together with it in nature.
- 1.23 There is simply no space in the periodic table for another element having an atomic number less than 92. All the elements from atomic number 1 (hydrogen) to atomic number 92 (uranium) have been discovered and accounted for. The only new elements that will be discovered are those with high atomic numbers. At present, the elements up to an atomic number of 118 are known. Any new elements will have atomic numbers greater than this.
- 1.24
 - (a) I
 - (b) W
 - (c) Xe
 - (d) Sm
 - (e) Pu
- 1.25 ductility
- 1.26 malleability
- 1.27 oxygen (O₂), nitrogen (N₂), fluorine (F₂), chlorine (Cl₂)
- 1.28 mercury and bromine
- 1.29 Lv is more likely, given its position on the periodic table.

- 1.30 Refer to figure 1.16 in the textbook.
- 1.31 Orbital. An orbital is a region in space where there is a non-zero probability of finding an electron.
- 1.32 Both NO and NO₂ must have unpaired spins, because they have a total of 15 and 23 electrons, respectively; both odd numbers. The other molecules all have an even number of electrons.
- 1.33 Atoms in excited states can emit excess energy as light (photons).
- 1.34 Quantisation generally involves energies that are miniscule with respect to the macroscopic world. Therefore, even though quantisation does occur, we cannot relate to it.

Review problems

- 1.35 Compound (c). An authentic sample of methane must have a mass ratio of carbon/hydrogen of 1.000 to 0.336. The only possibility in this list is therefore (c).
- 1.36 Compound (d). An authentic sample of calcium chloride must have a ratio of 1.00 to 1.77. The only possibility in the list is (d) which has the ratio of the mass of chlorine to calcium of $2.39/1.35 = 1.77$.
- 1.37 98.5 g chlorine. From the mass ratio given we must multiply the mass of carbon by 11.8 to obtain the mass of chlorine.
- 1.38 The given mass ratio of phosphorus to chlorine is 1.20 : 4.12. Dividing both numbers by 1.20 gives the 'simpler' ratio 1.00 : 3.43. Dividing the mass of chlorine by 3.43, we find that for every 6.22 g chlorine there will be 1.81 g phosphorus.
- 1.39 64.0 g of carbon tetrachloride. We know the carbon to chlorine mass ratio is 1.00 : 11.8. Multiplying 5.00 g by 11.8 gives 59.0 g of chlorine. Thus, the mass of carbon tetrachloride will be $5.00 \text{ g} + 59.0 \text{ g} = 64.0 \text{ g}$.
- 1.40 55.4 g of phosphorus chloride. From the ratio in problem 1.38, we know that the phosphorus to chlorine mass ratio is 1.00 : 3.43. Multiplying 12.5 g by 3.43 gives 42.9 g chlorine. Thus, the mass of phosphorus chloride formed will be $12.5 \text{ g} + 42.9 \text{ g} = 55.4 \text{ g}$.
- 1.41 2.664 g oxygen. If there are twice as many oxygen atoms per carbon atom, there must be twice the mass of oxygen per mass of carbon ($2 \times 1.332 \text{ g}$).
- 1.42 The ratio should be $4/2 = 2/1$, as required by the formulae of the two compounds. The mass of chlorine in compound 2 would be $2 \times 0.597 \text{ g Cl} = 1.19 \text{ g Cl}$.
- 1.43 $12 \times 1.660\,540\,2 \times 10^{-24} \text{ g} = 1.992\,648\,2 \times 10^{-23} \text{ g}$ for one ^{12}C atom
- 1.44 $23 \times 1.660\,540\,2 \times 10^{-24} \text{ g} = 3.819\,246\,6 \times 10^{-23} \text{ g}$ for one ^{23}Na atom
- 1.45 As there are 2 atoms of nitrogen in a molecule of nitrous oxide, dividing the mass of nitrogen by 2 will give the mass ratio of one atom of nitrogen to one atom of oxygen. This is 0.875 65. Multiplying this by 16.00, the atomic mass of ^{16}O , gives the atomic mass of nitrogen. Thus $16.00 \times 0.875\,65 = 14.01 \text{ u}$.
- 1.46 We are told that the formula of the compound is X_2O_3 and that in this compound, 1.125 g of X is combined with 1.000 g of O. From these data, we can calculate the ratio of the masses of X and O as being $\frac{1.125}{2} : \frac{1.000}{3} = 0.5625 : 0.3333$. This means $\frac{0.5625}{0.3333}$ that a single atom of X will be 0.3333 times as heavy as a single atom of O. We know the atomic mass of O is 15.9994 u, so the atomic mass of X will be $\frac{0.5625}{0.3333} \times 15.9994 \text{ u} = 27.00 \text{ u}$. The unknown element X is therefore aluminium.

- 1.47 2.0158 u. Regardless of the definition, the ratio of the mass of hydrogen to that of oxygen is the same. If ^{12}C is assigned a mass of 24 u (twice its accepted value), then hydrogen would also have a mass twice its accepted value.
- 1.48 Taking the mass ratio of ^{109}Ag to ^{12}C and multiplying it by 12, we see that the mass of ^{109}Ag is 108.90 u.
- 1.49 The average atomic mass is the sum of the mass of each isotope multiplied by its abundance. Therefore, the average atomic mass of antimony = $(0.5736 \times 120.9038 \text{ u}) + (0.4264 \times 122.9042 \text{ u}) = 121.8 \text{ u}$
- 1.50 (a) 138 neutrons, 88 protons, 88 electrons
(b) 8 neutrons, 6 protons, 6 electrons
(c) 124 neutrons, 82 protons, 82 electrons
(d) 12 neutrons, 11 protons, 11 electrons
- 1.51 (a) 52 neutrons, 38 protons, 38 electrons
(b) 33 neutrons, 27 protons, 27 electrons
(c) 15 neutrons, 15 protons, 15 electrons
(d) 16 neutrons, 14 protons, 14 electrons
- 1.52 Make use of the periodic table to match these correctly:
(a) Sr: it is the only group 2 element in the list
(b) In: elements in the same column as Al have similar chemical properties
(c) Co: transition metals lie in the *d* block
(d) Ne: noble gases are in group 18
(e) Pu: actinoids are in the *f* block
- 1.53 Consult the periodic table to find examples of various classes of elements.
(a) Nonmetals lie to the right of the periodic table — they are the elements in green in figure 1.16. Therefore, any three of the following elements will give a correct answer: He, C, N, O, F, Ne, P, S, Cl, Ar, Se, Br, Kr, I, Xe, At, Rn.
(b) Alkaline earth metals are in group 2. Therefore, any three of the following elements will give a correct answer: Be, Mg, Ca, Sr, Ba, Ra.
(c) Elements 57–71 are lanthanoids. Therefore, any three of the following elements will give a correct answer: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu.
(d) Chalcogens are in group 16. Therefore, any three of the following elements will give a correct answer: O, S, Se, Te, Po.

Additional exercises

- 1.54 (a) a metal
 (b) ^{55}Mn
 (c) 30
 (d) 25
 (e) approximately 4.58 times heavier — ^{55}Mn has an atomic mass of 54.94 u

- 1.55 From the data given, we can obtain the mass ratios $X : Y$, and $X : \text{O}$. Knowing the atomic mass of O allows us to calculate the atomic masses of X and Y .

$$\text{mass ratio } X : Y = 1 : \frac{0.684}{4} = 1 : 0.171$$

$$\text{mass ratio } X : \text{O} = 1 : \frac{0.154}{2} = 1 : 0.0770$$

The latter result means that an atom of O is 0.0770 times as heavy as an atom of X . Knowing that the atomic mass of O = 15.999 u, we can calculate the atomic mass of X from the equation:

$$\text{atomic mass of } X = \frac{1}{0.0770} \times 15.999 \text{ u} = 207.8 \text{ u}$$

We can now use this value to find the atomic mass of Y . We know that the mass ratio $X : Y$ is 1 : 0.171 so an atom of Y weighs 0.171 times the mass of an atom of X . Therefore, the atomic mass of $Y = 0.171 \times 207.8 \text{ u} = 35.5 \text{ u}$. Knowing the atomic masses, you can use the periodic table to show that the compound XY_4 is PbCl_4 .

- 1.56 55.85 u. The average atomic is the sum of the mass of each isotope multiplied by its abundance. Therefore, the average atomic mass = $(0.0580 \times 53.9396 \text{ u}) + (0.9172 \times 55.93949 \text{ u}) + (0.0220 \times 56.9354 \text{ u}) + (0.0028 \times 57.9333 \text{ u}) = 55.85 \text{ u}$
- 1.57 As_2O_5 . From the problem we find the following ratios:

$$\frac{2 \text{ atoms As}}{3 \text{ atoms O}} \quad \text{and} \quad \frac{3.122 \text{ g As}}{1.000 \text{ g O}}$$

Therefore 3.122 g represents 2/3 as many arsenic atoms as oxygen atoms. To find the relative mass of arsenic to oxygen we can divide this number by 2 to get 1.561 for As and divide 1.000 by 3 to get 0.3333 for oxygen.

$$\frac{\text{mass of As atom}}{\text{mass of O atom}} = \frac{1.561 \text{ g As}}{0.3333 \text{ g O}} = \frac{4.683 \text{ g As}}{1.000 \text{ g O}}$$

In the unknown compound, there are 1.873 g As for every 1.000 g O. This represents 1.873/4.683 As atoms per O atom, or

$$\frac{\frac{1.873}{4.683} \text{ atoms As}}{1 \text{ atom O}} = \frac{0.40 \text{ atoms As}}{1 \text{ atom O}} = \frac{2 \text{ atoms As}}{5 \text{ atoms O}}$$

- 1.58 Mass of 1 atom of Mg = $1.66\,054 \times 10^{-24} \text{ g} \times 24.305 = 4.0359 \times 10^{-23} \text{ g}$
 Mass of 1 atom of Fe = $1.660\,54 \times 10^{-24} \text{ g} \times 55.847 = 9.2736 \times 10^{-23} \text{ g}$

$$\text{In } 24.305 \text{ g of Mg, there will be } \frac{24.305 \text{ g}}{4.0359 \times 10^{-23} \text{ g}} = 6.0222 \times 10^{23} \text{ atoms of Mg}$$

$$\text{In } 55.847 \text{ g of Fe, there will be } \frac{55.847 \text{ g}}{9.2736 \times 10^{-23} \text{ g}} = 6.0221 \times 10^{23} \text{ atoms of Fe}$$

The answers are essentially the same. We can therefore assume that in 40.078 g of Ca, there are approximately 6.022×10^{23} atoms of Ca.

- 1.59 We assume that a typical atom is spherical. The volume of a sphere is given by the

$$V = \frac{4}{3}\pi r^3$$

equation

Therefore, the volume enclosed by the nucleus is:

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi (0.5 \times 10^{-15} \text{ m})^3 \approx 5 \times 10^{-46} \text{ m}^3$$

The volume enclosed by the atom is:

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi (0.5 \times 10^{-10} \text{ m})^3 \approx 5 \times 10^{-31} \text{ m}^3$$

Therefore, there is a factor of 10^{15} difference between the volume occupied by the nucleus and the total volume of the atom.

- 1.60 helium, neon, argon, krypton, xenon and radon exist as discrete atoms X .

hydrogen, nitrogen, oxygen, fluorine and chlorine exist as diatomic molecules X_2 .

- 1.61 (a) F^- contains $9 + 1 = 10$ electrons
 (b) O_2^- contains $(2 \times 8) + 1 = 17$ electrons
 (c) CO_3^{2-} contains $6 + (3 \times 8) + 2 = 32$ electrons
 (d) Na^+ contains $11 - 1 = 10$ electrons
 (e) PO_4^{3-} contains $15 + (4 \times 8) + 3 = 50$ electrons
 (f) ClO_4^- contains $17 + (4 \times 8) + 1 = 50$ electrons

- 1.62 (a) O^{2-}
 (b) F^-
 (c) Li^+
 (d) Be^{2+}
 (e) K^+
 (f) Br^-
 (g) I^-
 (h) Sr^{2+}