DETAILED ANSWERS
to STOICHIOMETRY-1 and EQUATIONS PROBLEMS

NOTE: Detailed workings are not given in questions where a detailed answer is already printed at the end of the problem set. 'INTRO' refers to the introductory section printed at the beginning of the assigned problems, where a number of the stoichiometry problems are solved in detail.
Further NOTE: Don't worry if your answer differs in last significant figure from that given here. Small differences arising from 'rounding off' or the use of atomic weights, etc., to different numbers of S.F. may be ignored.

Take the value of the Avogadro Constant, N_A, as 6.02×10^{23} mol^{-1}.

1. An organic compound has molecular formula C_2H_6O. For this compound:

(a) what is the molar mass? 46.07

(b) what is the mass of one molecule (i) in amu 46.07 amu, (ii) in g? $46.07 / N_A$ g

(c) how many atoms are there in the molecule? 9

(d) how many atoms are there in one mole of C_2H_6O? $9 \times N_A$

(e) how many mol of C_2H_6O are present in 100 g of the compound?

$100 / 46.07 = 2.17$ mol

(f) how many H atoms are there in 100 g of C_2H_6O?

2.17 mol as (e) with 6 H atoms per mole $2.17 \times 6 = 13.02$ mol H

contains $13.02 \times N_A$ H atoms

(g) what is the *mass* % of carbon in this compound? $100 \times 2 \times 12.01 / 46.07 = 52.2\%$

(h) what is the mole fraction of C atoms in the molecule of C_2H_6O? $2 / 9 = 0.222$

(i) what is the *mole* % of carbon in this compound? $100 \times 2 / 9$

(j) how many mol of C_2H_6O contain 100 mol of atoms (total all elements)?

nine mol of atoms in each mol, $100 / 9 = 11.1$

(k) what is the mass of deuterium, ${}^{2}_{1}H$ or D, present in 100 g of C_2H_6O?

The abundance of deuterium in natural hydrogen is 1.4×10^{-2} atom %.

Take the atomic mass of deuterium as 2.0 g mol^{-1}. As in (f), 13.02 mol H,

so mol of D = $13.02 \times 1.4 \times 10^{-2} / 100 = 1.82 \times 10^{-3}$ mol

mass 1.82×10^{-3} mol $\times$ 2.0 g mol^{-1} = 3.6×10^{-3} g D

2. How many mol of *ions* are present in total in each of the following?

(a) 1.00 mol of NaBr (b) 0.400 mol of $CaCl_2$

(c) 2.50 mol of $(NH_4)_2SO_4$ (d) 0.500 mol of K_3PO_4

as answers given, see also INTRO, p. 12

3. A stainless steel alloy contains 5.0% nickel by mass.

(a) What mass of nickel is contained in 1.8 kg of the alloy?

$1.8 \times 5.0 / 100 = 0.090$ kg or 90 g Ni

(b) What mass of the alloy would contain one mole of nickel?

one mol, 58.7 g Ni, in $58.7 \times 100 / 5.0 = 1174$ g or 1.17 kg alloy

4. Natural gallium contains two isotopes. 60.4 atom % is in the form of ^{69}Ga, molar mass 68.926 g mol^{-1}. What is the mass number of the other gallium isotope?

Suppose the mass of the other isotope is x, then we can write:

$(68.926 \times 60.4 / 100) + (x \times 39.6 / 100) = 69.71$ [known av at mass of Ga]

whence $x = 70.9$ and the mass number is 71

5. A element Q forms a chloride QCl_3 containing 46.62% chlorine by mass.

Calculate the atomic weight of the element.

Referring to the Periodic Table, identify element Q.

53.38 g Q combines 46.62 g Cl

$53.38 \times (3 \times 35.45) / 46.62$ combines 3 mol Cl in one mol QCl_3

one mol Q mass 121.8 g; Q must be Antimony, Sb

6. Consider the reaction by which HF dissolves glass:

$$SiO_2 + 4\,HF \rightarrow SiF_4 + 2\,H_2O$$

(a) To react with 256 g of SiO_2, what quantity of HF is required in (i) mol (ii) g

$256 / 60.1 = 4.26$ mol, needs $4 \times 4.26 = 17.0$ mol, $17.0 \times 20.0 = 341$ g HF

(b) Suppose 300 g of SiO_2 were dissolved in excess HF.

What quantity of SiF_4 would be produced, measured in (i) mol (ii) g?

$300 / 60.1 = 4.99$ mol SiO_2, gives 4.99 mol SiF_4,

mass $4.99 \times 104.1 = 520$ g

7. A compound contains carbon, hydrogen, and oxygen only. When a sample of mass 0.246 g is burned in excess oxygen, 0.600 g of CO_2 and 0.080 g of H_2O are produced. (a) Calculate the empirical formula.

(b) Given that the molar mass is about 160 g mol^{-1}, what is the molecular formula?

see detailed answer, INTRO p. 9

8. Natural bromine consists of two isotopes:

^{79}Br, mass 78.9183 g mol^{-1}, 50.69 atom % abundance

^{81}Br, mass 80.9163 g mol^{-1}, 49.31 atom % abundance

Calculate the average atomic mass of natural bromine to the appropriate number of significant figures.

$(78.9183 \times 50.69 / 100) + (80.9163 \times 49.31 / 100) = 79.90$ 4 S.F.

9. (a) The mass composition of a compound is found to be:

C, 53.31%; H, 11.19%; O, 35.51%

Calculate the empirical (simplest) formula. Another experiment shows the molar mass to be 90 ±4 g mol^{-1}. Calculate the molecular formula and the accurate molar mass.

divide by atomic weights, giving C, 4,439; H, 11.10; O, 2.219 mol

divide by smallest, C_2H_5O

formula weight of empirical formula is 45, so 90 / 45 = 2

molecular formula $C_4H_{10}O_2$, molar mass 90.12 g mol^{-1}

(b) A compound contains carbon and hydrogen only. On combustion, 0.150 g of the compound gives 0.488 g CO_2 and 0.150 g H_2O. The molar mass is found to be 52 ± 5 g mol^{-1}. Calculate the empirical and molecular formula of the compound.

0.488 g CO_2 = 0.488 / 44.0 = 0.0111 mol, from 0.0111 mol C

0.150 g H_2O = 0.150 / 18.0 = 0.00833 mol,

from 0.00833 × 2 = 0.0167 mol H

H / C ratio 0.0167 / 0.0111 = 1.50, simplest formula C_2H_3, formula weight 27 g mol^{-1}

molecular formula C_4H_6 (molar mass 54.0 g mol^{-1})

10. Electrolysis of brine produces three products according to the equation:

$2\ NaCl(aq) + 2\ H_2O \rightarrow H_2(g) + Cl_2(g) + 2\ NaOH(aq)$

If 2550 g of NaCl is electrolysed, what quantity of each product would be obtained? Express your answers in both mol and g amounts.

2550 / 58.5 = 43.6 mol NaCl. Gives 43.6 / 2 = 21.8 mol H_2, 43.9 g

43.6 / 2 mol Cl_2, mass 1.55 kg and 43.6 mol NaOH, mass 1.75 kg

11. A compound contains carbon, hydrogen, and oxygen only. When a sample of mass 1.60 g is burned in excess oxygen, 2.20 g of CO_2 and 1.80 g of H_2O are produced.

(a) What is the mass percentage of oxygen in the compound?

2.20 g CO_2 is 2.20 / 44.0 = 0.0500 mol CO_2

from 0.0500 mol C in compound, mass 0.0500 × 12.0 = 0.600 g C

1.80 g H_2O is 1.80 / 18.0 = 0.100 mol H_2O

from 0.100 × 2 = 0.200 mol H, mass 0.200 × 1.01 = 0.202 g H

By difference, mass of oxygen in sample 1.60 – 0.600 – 0.20 = 0.80 g O

100 × 0.80 / 1.60 = 50% oxygen by mass

(b) Calculate the empirical formula.

mol of oxygen 0.80 / 16 = 0.050 mol,

combining ratio is 0.0500:0.200:0.0500, 1 : 4 : 1 or CH_4O

12. A compound is analyzed for its bromine content by converting all bromine to AgBr. If a sample of the compound of mass 0.295 g gave 0.668 g of AgBr on analysis, what was the mass percent of bromine present?

0.668 g AgBr is 0.668 / 187.7 = 3.56×10^{-3} mol AgBr

1:1 stoich, comes from 3.56×10^{-3} mol Br in the compound

mass of Br in compound $3.56 \times 10^{-3} \times 79.9$ = 0.284 g Br

% Br = 100 × 0.284 / 0.295 = 96.3% by mass

13. The body's only use for the element fluorine is in tooth enamel, which consists of *fluorapatite*, $Ca_5(PO_4)_3F$. Use of a fluoridated toothpaste converts *hydroxyapatite*, $Ca_5(PO_4)_3(OH)$, into fluorapatite. If you convert 0.50 g of hydroxyapatite into fluorapatite, what mass of fluorine have you incorporated into your teeth?

0.50 g $Ca_5(PO_4)_3(OH)$ is 0.50 / 500 = 1.0×10^{-3} mol

1:1 stoich; incorporates 1.0×10^{-3} mol F,

mass $1.0 \times 10^{-3} \times 19.0$ = 0.019 g F

14. The gaseous pollutant SO_2 can be removed from flue gas by reaction with MgO:

$$SO_2 + H_2O + \tfrac{1}{2} O_2 \rightarrow H_2SO_4$$

$$MgO + H_2SO_4 \rightarrow MgSO_4 + H_2O$$

The MgO is obtained by strong heating of $MgCO_3$:

$$MgCO_3 \rightarrow MgO + CO_2$$

(a) What mass of $MgCO_3$ would be required to remove 1 kg of SO_2 from the flue gas?

1000 / 64.1 = 15.6 mol SO_2

stoich is 1:1 throughout, need 15.6 mol $MgCO_3$

mass 15.6 × 84.3 = 1320 g or 1.32 kg

(b) What mass of $MgSO_4$ would be produced by removal of 1 kg of SO_2?

still 1:1, produce 15.6 mol, mass 15.6 × 120.4 = 1878 g or 1.88 kg

15. A sample of lead, mass 2.07 g, is dissolved in nitric acid to give a solution of lead nitrate, $Pb(NO_3)_2$. When this is made basic, $Pb(OH)_2$ precipitates. Oxidation of this compound gives PbO_2, which dissolves in HCl to yield $PbCl_4$. Addition of NH_4Cl then precipitates the complex salt $(NH_4)_2PbCl_6$. What is the maximum amount of the final compound that could be produced? [Hint: this problem is much easier than it looks!]

start with 2.07 / 207 = 0.0100 mol Pb, *ignoring all the intermediate steps,*

one mol $(NH_4)_2PbCl_6$ must come from one mol of Pb

obtain 0.0100 mol $(NH_4)_2PbCl_6$, mass 4.56 g

16. A certain compound is known to contain C, N, and S only. When a sample of mass 1.68 g is burned in excess oxygen 1.76 g of CO_2 is produced. In another experiment, a sample of the compound of mass 0.561 g is burned and the sulfur present converted to 1.56 g of $BaSO_4$. Calculate the empirical formula of the compound.

see detailed answer, INTRO p. 10,11

17. A metal M forms the oxide M_2O_3, which contains 68.42% by mass of metal M. Calculate the atomic weight of the metal. Referring to the Periodic Table, identify the metal M.

68.42 g of metal combine with 31.58 g O. Therefore there are

68.42 × 48.0 / 31.58 g metal and 3 mol (48.0 g) oxygen in one mol M_2O_3

104.0 g metal represents M_2.

Molar mass of metal 104.0 / 2 = 52.0 g mol^{-1}

from table, M must be Chromium, Cr

18. Biphenyl is an aromatic hydrocarbon of formula $C_{12}H_{10}$. Chlorination gives compounds known as *polychlorinated biphenyls*, or PCB's, general formula $C_{12}H_mCl_{(10-m)}$.
If a PCB contains 58.9% chlorine by mass, what is the value of m in its formula?
(*Hint:* work out the % Cl in terms of m; put the expression equal to 58.9)

In one mole: mass of Cl = $35.45(10 - m)$ g

molar mass $(12 \times 12.01) + 1.008m + 35.45(10 - m)$ g

% Cl = $100 \times 35.45(10 - m) / [(12 \times 12.01) + 1.008m + 35.45(10 - m)] = 58.9$

solving, $m = 4$

19. Nitric acid is produced commercially from ammonia by a three-stage process:

$$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$$
$$2\ NO + O_2 \rightarrow 2\ NO_2$$
$$3\ NO_2 + H_2O \rightarrow 2\ HNO_3 + NO$$

(a) Combine these equations to give an overall reaction is which ammonia is converted to nitric acid as the *only* nitrogen-containing product (i.e., no oxides of nitrogen).
The suggested method is to eliminate NO_2 between the second and third equation, then eliminate NO between the resulting equation and the first equation.
(b) Assuming 100% yield, what mass of NH_3 would be needed to make 1.00 kg HNO_3?

1.00 kg is 1000 / 63.0 = 15.9 mol HNO_3

1:1 stoich; comes from 15.9 mol NH_3, mass $15.9 \times 17.0 = 270$ g

20. A metal M forms the oxide M_2O. Reduction of 28.6 g M_2O yields 25.4 g of metal M.
Calculate the molar mass of M and identify the metal.

by difference, sample contained $28.6 - 25.4 = 3.2$ g oxygen

25.4 g metal combined with 3.2 g O. Therefore in one mol oxide,

$25.4 \times 16.0 / 3.2 = 127$ g metal combined with 16.0 g O

127 g represents 2 mol of metal in formula M_2O

molar mass of M 127 / 2 = 63.5, and oxide must be Cu_2O

21. It was once thought (mistakenly) that compounds known as *boron hydrides* would be suitable as rocket fuels. The following reaction of *pentaborane* may be postulated:

$$2\ B_5H_9\ (l)\ +\ 12\ O_2(l)\ \rightarrow\ 5\ B_2O_3(s)\ +9\ H_2O(l)$$

If a tank of pentaborane has a volume of 1000 L, what volume should the tank of liquid oxygen be to ensure that stoichiometric quantities of the two reactants were carried and nothing remained unreacted at the completion of combustion?

(Densities of the liquids are: $B_5H_9(l)$, 0.637; $O_2(l)$, 1.118 g mL^{-1})

1000 L × 637 g L^{-1} [note units] = 6.37×10^5 g B_5H_9

that is $6.37 \times 10^5 / 63.0 = 1.01 \times 10^4$ mol B_5H_9

from equation, reacts with $1.01 \times 10^4 \times 12 / 2 = 6.07 \times 10^4$ mol O_2

of mass $6.07 \times 10^4 \times 32.0 = 1.94 \times 10^6$ g

of volume (1.94×10^6 g) / (1118 g L^{-1}) = 1733 L

22. What mass of sulfur must be burned to yield enough SO_2 to react with 1 L of a solution of NaOH which contains 8.00% by mass of NaOH and has a density of 1.087 g mL^{-1} ? What mass of $NaHSO_3$ would be produced?

see detailed answer, INTRO, p. 11,12

23. Magnesium is added to aluminum before fabrication to improve its strength. When a sample of a Mg / Al alloy of mass 1.00 g is dissolved in excess acid, 0.0527 mol of H_2 is evolved. What is the composition of the alloy by mass?

(*Hint:* reactions of Mg and Al with acid give Mg^{2+} and Al^{3+} respectively.)

We have to write *two separate equations* for the reactions of the metals.

$Mg(s)\ +\ 2\ H^+\ \rightarrow\ Mg^{2+}\ +\ H_2(g)$

$Al(s)\ +\ 3\ H^+\ \rightarrow\ Al^{3+}\ +3/2\ H_2(g)$

1:1 for Mg to H_2, 1:1.5 for Al to H_2

see given answer for the ensuing arithmetic

24. A certain reaction has the stoichiometry:

$$A\ +\ 2\ B\ \rightarrow\ 2\ C\ +D$$

where the molar masses of A, C, and D are respectively 60, 50, and 120 g mol^{-1}.

What is the molar mass of compound B? What mass of compound B is required to produce 100 g of compound D? (*Hint:* remember the law of conservation of mass!)

see given answer

25. Considerable excitement has attended the discovery of an important nickel deposit at Voisey Bay in Labrador. A typical nickel ore contains about 2% by mass of a nickel polysulfide with approximate formula Ni_9S_8. If the nickel can be extracted with an efficiency of 80%, what mass of ore would have to be processed to produce 1 kg of nickel?

1 kg of Ni is 1000 / 58.7 = 17.0 mol

comes from 17.0 / 9 = 1.89 mol Ni_9S_8

mass 1.89 × 785.2 = 1486 g or 1.49 kg Ni_9S_8

if the efficiency of extraction is only 80%, we would need to start with

1.49 × 100 / 80 = 1.86 kg Ni_9S_8

this is contained in 1.86 × 100 / 2 = 93 kg ore