

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 $6.02 \times 10^{23} \text{ mol}^{-1}$.

1. An organic compound has molecular formula $\text{C}_2\text{H}_6\text{O}$. 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? $46.07 / N_A \text{ g}$
- (c) how many atoms are there in the molecule? 9
- (d) how many atoms are there in one mole of $\text{C}_2\text{H}_6\text{O}$? $9 \times N_A$
- (e) how many mol of $\text{C}_2\text{H}_6\text{O}$ are present in 100 g of the compound?
- $100 / 46.07 = 2.17 \text{ mol}$
- (f) how many H atoms are there in 100 g of $\text{C}_2\text{H}_6\text{O}$?
- 2.17 mol as (e) with 6 H atoms per mole $2.17 \times 6 = 13.02 \text{ mol H}$
- 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 $\text{C}_2\text{H}_6\text{O}$? $2 / 9 = 0.222$
- (i) what is the *mole* % of carbon in this compound? $100 \times 2 / 9$
- (j) how many mol of $\text{C}_2\text{H}_6\text{O}$ 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_1H or D, present in 100 g of $\text{C}_2\text{H}_6\text{O}$?
- The abundance of deuterium in natural hydrogen is $1.4 \times 10^{-2} \text{ atom \%}$.
- Take the atomic mass of deuterium as 2.0 g mol^{-1} . As in (f), 13.02 mol H,
- so mol of D = $13.02 \times 1.4 \times 10^{-2} / 100 = 1.82 \times 10^{-3} \text{ mol}$
- mass $1.82 \times 10^{-3} \text{ mol} \times 2.0 \text{ g mol}^{-1} = 3.6 \times 10^{-3} \text{ g D}$

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 CaCl₂
(c) 2.50 mol of (NH₄)₂SO₄ (d) 0.500 mol of K₃PO₄

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?

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

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

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

4. Natural gallium contains two isotopes. 60.4 atom % is in the form of ⁶⁹Ga, 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:

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

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

5. A element Q forms a chloride QCl₃ containing 46.62% chlorine by mass.

Calculate the atomic weight of the element.

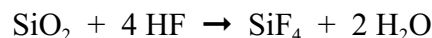
Referring to the Periodic Table, identify element Q.

$$53.38 \text{ g Q combines } 46.62 \text{ g Cl}$$

$$53.38 \times (3 \times 35.45) / 46.62 \text{ combines } 3 \text{ mol Cl in one mol QCl}_3$$

$$\text{one mol Q mass } 121.8 \text{ g; Q must be Antimony, Sb}$$

6. Consider the reaction by which HF dissolves glass:



(a) To react with 256 g of SiO₂, what quantity of HF is required in (i) mol (ii) g

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

(b) Suppose 300 g of SiO₂ were dissolved in excess HF.

What quantity of SiF₄ would be produced, measured in (i) mol (ii) g?

$$300 / 60.1 = 4.99 \text{ mol SiO}_2, \text{ gives } 4.99 \text{ mol SiF}_4,$$

$$\text{mass } 4.99 \times 104.1 = 520 \text{ g}$$

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 CO₂ and 0.080 g of H₂O 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 $78.9183 \text{ g mol}^{-1}$, 50.69 atom % abundance

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

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

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

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 $90 \pm 4 \text{ g mol}^{-1}$. Calculate the molecular formula and the accurate molar mass.

divide by atomic weights, giving C, 4.439; H, 1.10; O, 2.219 mol

divide by smallest, $\text{C}_2\text{H}_5\text{O}$

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

molecular formula $\text{C}_4\text{H}_{10}\text{O}_2$, 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 $52 \pm 5 \text{ g mol}^{-1}$. Calculate the empirical and molecular formula of the compound.

$0.488 \text{ g CO}_2 = 0.488 / 44.0 = 0.0111 \text{ mol}$, from 0.0111 mol C

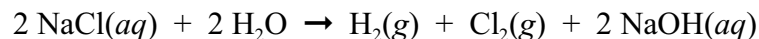
$0.150 \text{ g H}_2\text{O} = 0.150 / 18.0 = 0.00833 \text{ mol}$,

from $0.00833 \times 2 = 0.0167 \text{ mol H}$

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:



If 2550 g of NaCl is electrolysed, what quantity of each product would be obtained?

Express your answers in both mol and g amounts.

$2550 / 58.5 = 43.6 \text{ mol NaCl}$. Gives $43.6 / 2 = 21.8 \text{ mol H}_2$, 43.9 g

$43.6 / 2 \text{ mol Cl}_2$, 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 CO₂ and 1.80 g of H₂O are produced.

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

$$2.20 \text{ g CO}_2 \text{ is } 2.20 / 44.0 = 0.0500 \text{ mol CO}_2$$

$$\text{from } 0.0500 \text{ mol C in compound, mass } 0.0500 \times 12.0 = 0.600 \text{ g C}$$

$$1.80 \text{ g H}_2\text{O is } 1.80 / 18.0 = 0.100 \text{ mol H}_2\text{O}$$

$$\text{from } 0.100 \times 2 = 0.200 \text{ mol H, mass } 0.200 \times 1.01 = 0.202 \text{ g H}$$

By difference, mass of oxygen in sample $1.60 - 0.600 - 0.20 = 0.80 \text{ g O}$

$$100 \times 0.80 / 1.60 = 50\% \text{ oxygen by mass}$$

(b) Calculate the empirical formula.

$$\text{mol of oxygen } 0.80 / 16 = 0.050 \text{ mol,}$$

$$\text{combining ratio is } 0.0500:0.200:0.0500, 1 : 4 : 1 \text{ or CH}_4\text{O}$$

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?

$$0.668 \text{ g AgBr is } 0.668 / 187.7 = 3.56 \times 10^{-3} \text{ mol AgBr}$$

$$1:1 \text{ stoich, comes from } 3.56 \times 10^{-3} \text{ mol Br in the compound}$$

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

$$\% \text{ Br} = 100 \times 0.284 / 0.295 = 96.3\% \text{ by mass}$$

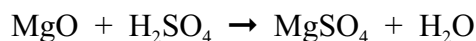
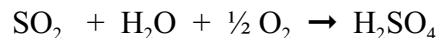
13. The body's only use for the element fluorine is in tooth enamel, which consists of *fluorapatite*, Ca₅(PO₄)₃F. Use of a fluoridated toothpaste converts *hydroxyapatite*, Ca₅(PO₄)₃(OH), into fluorapatite. If you convert 0.50 g of hydroxyapatite into fluorapatite, what mass of fluorine have you incorporated into your teeth?

$$0.50 \text{ g Ca}_5(\text{PO}_4)_3(\text{OH}) \text{ is } 0.50 / 500 = 1.0 \times 10^{-3} \text{ mol}$$

$$1:1 \text{ stoich; incorporates } 1.0 \times 10^{-3} \text{ mol F,}$$

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

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



The MgO is obtained by strong heating of MgCO_3 :



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

$$1000 / 64.1 = 15.6 \text{ mol } \text{SO}_2$$

stoich is 1:1 throughout, need 15.6 mol MgCO_3

$$\text{mass } 15.6 \times 84.3 = 1320 \text{ g or } 1.32 \text{ kg}$$

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

$$\text{still } 1:1, \text{ produce } 15.6 \text{ mol, mass } 15.6 \times 120.4 = 1878 \text{ g or } 1.88 \text{ kg}$$

15. A sample of lead, mass 2.07 g, is dissolved in nitric acid to give a solution of lead nitrate, $\text{Pb}(\text{NO}_3)_2$. When this is made basic, $\text{Pb}(\text{OH})_2$ 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 $(\text{NH}_4)_2\text{PbCl}_6$. What is the maximum amount of the final compound that could be produced? [Hint: this problem is much easier than it looks!]

start with $2.07 / 207 = 0.0100 \text{ mol Pb}$, *ignoring all the intermediate steps*,

one mol $(\text{NH}_4)_2\text{PbCl}_6$ must come from one mol of Pb

obtain 0.0100 mol $(\text{NH}_4)_2\text{PbCl}_6$, 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

$68.42 \times 48.0 / 31.58 \text{ g metal}$ and 3 mol (48.0 g) oxygen in one mol M_2O_3

104.0 g metal represents M_2 .

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

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)

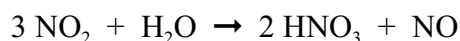
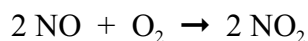
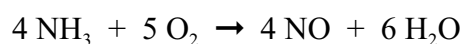
In one mole: mass of Cl = $35.45(10 - m)$ g

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

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

solving, $m = 4$

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



(a) Combine these equations to give an overall reaction in 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 ?

$$1.00 \text{ kg is } 1000 / 63.0 = 15.9 \text{ mol HNO}_3$$

$$1:1 \text{ stoich; comes from } 15.9 \text{ mol NH}_3, \text{ mass } 15.9 \times 17.0 = 270 \text{ g}$$

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

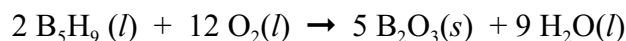
25.4 g metal combined with 3.2 g O. Therefore in one mol oxide,

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

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:



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: $\text{B}_5\text{H}_9(l)$, 0.637; $\text{O}_2(l)$, 1.118 g mL⁻¹)

$$1000 \text{ L} \times 637 \text{ g L}^{-1} [\text{note units}] = 6.37 \times 10^5 \text{ g B}_5\text{H}_9$$

$$\text{that is } 6.37 \times 10^5 / 63.0 = 1.01 \times 10^4 \text{ mol B}_5\text{H}_9$$

$$\text{from equation, reacts with } 1.01 \times 10^4 \times 12 / 2 = 6.07 \times 10^4 \text{ mol O}_2$$

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

$$\text{of volume } (1.94 \times 10^6 \text{ g}) / (1118 \text{ g L}^{-1}) = 1733 \text{ L}$$

22. What mass of sulfur must be burned to yield enough SO₂ 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?

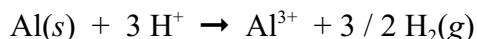
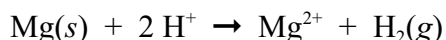
What mass of NaHSO₃ would be produced?

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 H₂ is evolved. What is the composition of the alloy by mass?

(Hint: reactions of Mg and Al with acid give Mg²⁺ and Al³⁺ respectively.)

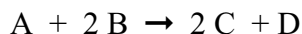
We have to write *two separate equations* for the reactions of the metals.



1:1 for Mg to H₂, 1:1.5 for Al to H₂

see given answer for the ensuing arithmetic

24. A certain reaction has the stoichiometry:



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 $1.89 \times 785.2 = 1486$ g or 1.49 kg Ni_9S_8

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

$1.49 \times 100 / 80 = 1.86$ kg Ni_9S_8

this is contained in $1.86 \times 100 / 2 = 93$ kg ore