W1 WORKSHOP ON STOICHIOMETRY
worked answers to workshop

Q1. Calculate the mass of 2.0 mol of silicon.

Atomic mass of Si = 28.09

Mass of 2 mol of Si = 2.0 × 28.09 = 56.18 = 56 g (2 significant figures)

Q2. Calculate the mass of 0.37 mol of barium chloride.

Formula weight of $BaCl_2$ = 137.3 (Ba) + (2 × 35.45 (Cl)) = 208.2

Mass of 0.37 mol of $BaCl_2$ = 0.37 × 208.2 = 77.034 = 77 g (2 significant figures)

Q3. Calculate the amount (in mol) present in 2.8 g sulfur.

$$n = \frac{m}{M} = \frac{2.8}{32.07} = 0.08731 = 0.087 \text{ (2 significant figures)}$$

Q4. Calculate the amount (in mol) present in 36.0 g of water.

Molecular weight of water is 16.00 (O) + (2 × 1.008 (H)) = 18.016

$$n = \frac{m}{M} = \frac{36.0}{18.016} = 1.998 = 2.00 \text{ (3 significant figures)}$$

Q5. Calculate the mass of 6.022×10^{23} molecules of hydrogen.

Molecular weight of H_2 = 2 × 1.008 = 2.016

$$n = \frac{\text{number of atoms}}{\text{Avogadro's number}} = \frac{6.022 \times 10^{23}}{6.022 \times 10^{23}} = 1.000 = 1.000 \text{ mol}$$

$$m = n \times M = 1.000 \times 2.016 \text{ g} = 2.016 \text{ g (4 significant figures)}$$

Q6. Calculate the amount (in mol) present in 2.0×10^{20} molecules of carbon dioxide.

$$n = \frac{\text{number of atoms}}{\text{Avogadro's number}} = \frac{2.0 \times 10^{20}}{6.022 \times 10^{23}} = 3.321 \times 10^{-4} \text{ mol}$$

$$= 3.3 \times 10^{-4} \text{ mol (2 significant figures)}$$

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Q7. Calculate the amount (in mol) present in 5.6 L of argon at STP.

1 mol of any gas at STP occupies 22.4 L

$$\therefore \ \mathbf{5.6\ L\ of\ Ar} = \frac{\text{volume of gas (in L)}}{22.4\text{ L}} = \frac{5.6}{22.4} = 0.25 \text{ mol}$$

Q8. Calculate the mass of 50.0 L of nitrogen gas at STP.

1 mol of any gas at STP occupies 22.4 L

$$\therefore \ \mathbf{50.0\ L\ of\ N_2} = \frac{\text{volume of gas (in L)}}{22.4\text{ L}} = \frac{50.0}{22.4} = 2.232 \text{ mol}$$

Molecular weight of N_2 = 2 × 14.01 = 28.02

m = n × M = 2.232 × 28.02 = 62.545 = 62.5 g (3 significant figures)

Q9. Calculate the atomic weight and the molecular weight of a natural sample of chlorine, which contains the isotopes: ^{35}Cl (at. wt. 34.97, 75.77%) and ^{37}Cl (at. wt. 36.97, 24.23%).

The relative atomic mass of chlorine is the weighted average of the masses of its isotopes:

$$\left(34.97 \times \frac{75.77}{100}\right) + \left(36.97 \times \frac{24.23}{100}\right) = 35.45 \text{ (4 significant figures)}$$

Molecular weight of Cl_2 = 35.45 × 2 = 70.90

Q10. Determine the percentage by weight of bromide ion in potassium bromide (KBr).

Atomic weight of Br = 79.90 Atomic weight of K = 39.10

$$\text{\% weight of Br in KBr} = \frac{79.90}{(39.10 + 79.90)} = 67.14\%$$

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Q11. An iron ore has the composition of 70.0% Fe and 30.0% O by mass. What is the empirical formula of the ore?

	Fe	**O**
amount in 100 g	**70.0**	**30.0**
ratio (divide by atomic mass)	$\frac{70.0}{55.85} = 1.250$	$\frac{30.0}{16.00} = 1.875$
divide by smallest	$\frac{1.250}{1.250} = 1.000 \sim 1$	$\frac{1.875}{1.250} = 1.500 \sim 1.5$

The smallest integer ratio is 2: 3 so the empirical formula is Fe_2O_3

Q12. An organic compound containing only carbon, hydrogen and oxygen returns the % mass analysis: C 64.9 %; H 13.5 %. What is its empirical formula?

As the compound contains only C, H and O, their percentages by mass must add up to 100%. Hence, the percentage of O is 100 – (64.9 + 13.5) = 21.6 %

	C	**H**	**O**
amount in 100 g	**64.9**	**13.5**	**21.6**
ratio (divide by atomic mass)	$\frac{64.9}{12.01} = 5.404$	$\frac{13.5}{1.008} = 13.39$	$\frac{21.6}{16.00} = 1.350$
divide by smallest	$\frac{5.404}{1.350} = 4.00 \sim 4$	$\frac{13.39}{1.350} = 9.92 \sim 10$	$\frac{1.350}{1.350} = 1.00 \sim 1$

The empirical formula is $C_4H_{10}O$

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Q13. Balance each of the following molecular equations:

2C(s) + O_2(g) → **2**CO(g)
N_2(g) + **3**H_2(g) → **2**NH_3(g)
2Na(s) + Br_2(l) → **2**NaBr(s)
4Fe(s) + **3**O_2(g) → **2**Fe_2O_3(s)

Q14. Complete the following table. (See page E2-1 if you need help.)

Formula	Name	Formula	Name
OH^-	**hydroxide ion**	$\mathbf{CH_3CO_2^-}$	acetate ion
$\mathbf{NO_2^-}$	nitrite ion	CN^-	**cyanide ion**
$\mathbf{NO_3^-}$	nitrate ion	HS^-	**hydrogensulfide ion**
$C_2O_4^{2-}$	**oxalate ion**	$\mathbf{MnO_4^-}$	permanganate ion
$\mathbf{ClO_4^-}$	perchlorate ion	$\mathbf{HCO_3^-}$	hydrogencarbonate ion
$\mathbf{CO_3^{2-}}$	carbonate ion	$\mathbf{PO_4^{3-}}$	phosphate ion
$S_2O_3^{2-}$	**thiosulfate ion**	$H_2PO_4^-$	**dihydrogenphosphate ion**
$\mathbf{SO_4^{2-}}$	sulfate ion	$\mathbf{NH_4^+}$	ammonium ion
$\mathbf{SO_3^{2-}}$	sulfite ion	$Cr_2O_7^{2-}$	**dichromate ion**

Q15. Indicate the charges on the ions and balance the following ionic equations:

KI(s) → K^+(aq) + I^-(aq)
Na_2CO_3(s) → **2**Na^+(aq) + CO_3^{2-}(aq)
NH_4Cl(s) → NH_4^+(aq) + Cl^-(aq)
$Ca(OH)_2$(s) → Ca^{2+}(aq) + **2**OH^-(aq)

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Q16. Write the ionic equations for the reactions that occur when solid sodium carbonate and solid calcium chloride dissolve in water. Also write the ionic equation for the precipitation of calcium carbonate resulting from mixing the two solutions.

$Na_2CO_3(s) \rightarrow 2Na^+(aq) + CO_3^{2-}(aq)$
$CaCl_2(s) \rightarrow Ca^{2+}(aq) + 2Cl^-(aq)$
$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

Q17. Calculate the mass of sodium carbonate ($Na_2CO_3 \cdot 10H_2O$) required to make 250 mL of a 0.100 M solution.

$Na_2CO_3 \cdot 10H_2O$ has formula weight:

$(2 \times 22.99\ (Na)) + 12.01\ (C) + (3 \times 16.00\ (O)) + 10 \times (16.00\ (O) + 2 \times 1.008\ (H))$
$= 286.15$

1000 mL of 0.100 M solution contains 0.100 mol

250 mL of 0.100 M solution contains (0.100×0.250) mol of $Na_2CO_3 \cdot 10H_2O$

250 mL of 0.100 M solution contains $(0.100 \times 0.250) \times 286.15$ g of $Na_2CO_3 \cdot 10H_2O$
$= 7.15$ g (3 significant figures)

Q18. What mass of barium sulfate will be precipitated when 125 mL of a 0.20 M solution of barium chloride is mixed with 200 mL of a 0.17 M solution of sodium sulfate. (Hint: work out which reagent is limiting.)

$BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$

Amount of $BaCl_2 = 0.20 \times 0.125 = 0.025$ mol

Amount of $Na_2SO_4 = 0.17 \times 0.200 = 0.034$ mol

As *one* mole of $BaCl_2$ is required for every *one* mole of Na_2SO_4, $BaCl_2$ is the limiting reagent

Formula weight of $BaSO_4 = 137.3\ (Ba) + 32.07\ (S) + (4 \times 16.00\ (O)) = 233.37$

Mass of $BaSO_4$ precipitated $= 233.37 \times 0.025 = 5.834 = 5.8$ (2 significant figures)

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Q19. Pure formic acid (HCOOH), is a liquid monoprotic acid decomposed by heat to carbon dioxide and hydrogen, according to the following equation:

$$HCOOH(l) \rightarrow H_2(g) + CO_2(g)$$

(i) The density of formic acid is 1.220 g mL^{-1}. How many moles of HCOOH are in 1 L of pure formic acid?

Molecular weight of HCOOH = 12.01 (C) + (2 × 1.008 (H)) + (2 × 16.00 (O)) = 46.026

1 mL of HCOOH has mass 1.220 g

1000 mL of HCOOH has mass 1220 g

1000 mL of HCOOH contains 1220 / 46.026 = 26.51 mol (4 significant figures)

(ii) What mass of pure formic acid should be diluted to 1.00 L to form a 2.00 M solution?

Molecular weight of HCOOH = 12.01 (C) + (2 × 1.008 (H)) + (2 × 16.00 (O)) = 46.026

2.00 mol of HCOOH has mass 2.00 × 46.026 = 92.052 = 92.1 g (3 significant figures)

(iii) What volume of 0.250 M sodium hydroxide solution would react with 30.0 mL of this dilute solution of formic acid, according to the following equation?

$$HCOOH(aq) + OH^-(aq) \rightarrow HCOO^-(aq) + H_2O(l)$$

30.0 mL of 2.00 M HCOOH solution contains 2.00 × 0.0300 = 0.0600 mol of HCOOH

$$\textbf{Volume} = \frac{\textbf{number of moles (in mol)}}{\textbf{concentration (in M)}} = \frac{\textbf{0.0600}}{\textbf{0.250}} = \textbf{0.240 L = 240 mL (3 significant figures)}$$

(iv) What is the maximum volume of carbon dioxide at STP that could be obtained by heating 1.0 mol of formic acid?

From equation stoichiometry, 1 mol of HCOOH produces 1 mol of CO_2.

1 mol of any gas at STP has volume 22.4 L.

(v) How many molecules of carbon dioxide would it contain?

1 mol of any substance contains N_A molecules = 6.022 × 10^{23} molecules.

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Q20. Consider the reaction $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

Identify the limiting reagent in each of the following reaction mixtures. What mass of $Al_2O_3(s)$ will be produced in each case?

1.0 mol Al and 1.0 mol O_2 **Al is limiting** **4 mol of Al reacts with 3 mol of O_2 to give 2 mol of Al_2O_3** **Therefore 1 mol of Al reacts with $\frac{3}{4}$ mol of O_2 to give $\frac{2}{4}$ mol of Al_2O_3** **Formula weight of Al_2O_3 = (2 × 26.98 (Al)) + (3 × 16.00 (O)) = 101.96** **$\frac{2}{4}$ mol of Al_2O_3 has mass 101.96 × $\frac{2}{4}$ = 50.98 = 51 g (2 significant figures)**
0.75 mol Al and 0.50 mol O_2 **O_2 is limiting** **4 mol of Al reacts with 3 mol of O_2 to give 2 mol of Al_2O_3** **Therefore 4 × $\frac{0.5}{3}$ mol of Al react with 0.5 mol of O_2 reacts with to give 2 × $\frac{0.5}{3}$ mol of Al_2O_3** **Formula weight of Al_2O_3 = (2 × 26.98 (Al)) + (3 × 16.00 (O)) = 101.96** **2 × $\frac{0.5}{3}$ mol of Al_2O_3 has mass 101.96 × 2 × $\frac{0.5}{3}$ = 33.99 = 34 g (2 significant figures)**
75.89 g Al and 112.25 g O_2 **Amount of Al = $\frac{75.89}{26.98}$ = 2.8128 mol   Amount of O_2 = $\frac{112.25}{(2 \times 16.00)}$ = 3.5078 mol** **Al is limiting** **4 mol of Al reacts with 3 mol of O_2 to give 2 mol of Al_2O_3** **Therefore 2.813 mol of Al reacts with 3 × $\frac{2.813}{4}$ mol of O_2 to give 2 × $\frac{2.813}{4}$ mol of Al_2O_3** **Formula weight of Al_2O_3 = (2 × 26.98 (Al)) + (3 × 16.00 (O)) = 101.96** **2 × $\frac{2.813}{4}$ mol of Al_2O_3 has mass 101.96 × 2 × $\frac{2.813}{4}$ = 143.4 g (4 significant figures)**

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51.28 g Al and 48.22 g O_2

Amount of Al = $\frac{51.28}{26.98}$ **= 1.9007 mol** **Amount of O_2 =** $\frac{48.22}{(2 \times 16.00)}$ **= 1.5069 mol**

Al is limiting

4 mol of Al reacts with 3 mol of O_2 to give 2 mol of Al_2O_3

Therefore 1.9007 mol of Al reacts with 3 × $\frac{1.9007}{4}$ **mol of O_2 to give 2 ×** $\frac{1.9007}{4}$ **mol of Al_2O_3**

Formula weight of Al_2O_3 = (2 × 26.98 (Al)) + (3 × 16.00 (O)) = 101.96

2 × $\frac{1.9007}{4}$ **mol of Al_2O_3 has mass 101.96 × 2 ×** $\frac{1.9007}{4}$ **= 96.90 g (4 significant figures)**