UNIVERSITY OF CAMBRIDGE

STUDY PACK 1.3

AMOUNTS OF SUBSTANCES & VOLUMES OF GASES

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Balancing Equations

1	_ H_2	+	O_2	→	_ H_2O				
2	$BaCl_2$	+	_ NaOH	→	$Ba(OH)_2$	+	_ NaCl		
3	H_2SO_4	+	_ KOH	→	_ K_2SO_4	+	H_2O		
4	K_2CO_3	+	_ HCl	→	_KCl	+	H_2O	+	CO_2
5	$CaCO_3$	+	_HNO_3	→	$Ca(NO_3)_2$	+	H_2O	+	CO_2
6	Ca	+	_H_2O	→	$Ca(OH)_2$	+	H_2		
7	$Pb(NO_3)_2$	+	NaI	→	PbI_2	+	$NaNO_3$		
8	$Al_2(SO_4)_3$	+	NaOH	→	$Al(OH)_3$	+	Na_2SO_4		
9	$Al(OH)_3$	+	NaOH	→	$NaAlO_2$	+	H_2O		
10	$Pb(NO_3)_2$	→	PbO	+	NO_2	+	O_2		

11	$FeSO_4$	→	Fe_2O_3	+	SO_2	+	SO_3		
12	NH_4NO_3	→	N_2O	+	H_2O				
13	$NaNO_3$	→	$NaNO_2$	+	O_2				
14	CH_4	+	O_2	→	CO_2	+	H_2O		
15	C_4H_{10}	+	O_2	→	CO_2	+	H_2O		
16	PCl_3	+	H_2O	→	H_3PO_3	+	HCl		
17	$8HNO_3$	+	3Cu	→	$Cu(NO_3)_2$	+	NO	+	H_2O
18	$4HNO_3$	+	Cu	→	$Cu(NO_3)_2$	+	NO_2	+	H_2O
19	H_3PO_4	+	NaOH	→	NaH_2PO_4	+	H_2O		
20	H_3PO_4	+	NaOH	→	Na_3PO_4	+	H_2O		
21	H_3PO_4	+	NaOH	→	Na_2HPO_4	+	H_2O		
22	6NaOH	+	Cl_2	→	$NaClO_3$	+	NaCl	+	H_2O

Ionic equations

In questions 1–5 you are required to balance the equations, in questions 6–10 you are required to complete the equation and then balance it. For questions 1–17 you are required to write the full, balanced ionic equation. Questions 18–20 involve more complex ions again you are just asked to balance the equation.

1	$Pb^{2+}(aq)$	+	$OH^-(aq)$	→	$Pb(OH)_2(s)$					
2	$Al^{3+}(aq)$	+	$OH^-(aq)$	→	$Al(OH)_3(s)$					
3	$Al(OH)_3(s)$	+	$OH^-(aq)$	→	$AlO_2^{2-}(aq)$	+	$H_2O(l)$			
4	$Cl_2(g)$	+	$OH^-(aq)$	→	$ClO_3^{3-}(aq)$	+	$Cl^-(aq)$	+	$H_2O(l)$	
5	$S_2O_3^{2-}(aq)$	+	$I_2(s)$	→	$S_4O_6^{2-}(aq)$	+	$2I^-(aq)$			
6	$Cu^{2+}(aq)$	+	$OH^-(aq)$	→						
7	$CO_3^{2-}(s)$	+	$H^+(aq)$	→						
8	$Zn(s)$	+	$H^+(aq)$	→						
9	$Zn(s)$	+	$Pb^{2+}(aq)$	→						
10	$H^+(aq)$	+	$OH^-(aq)$	→						

11	Write an ionic equation for the reaction of magnesium with sulphuric acid.
12	Write an ionic equation for the reaction of sodium carbonate solution with nitric acid.
13	Write an ionic equation for the reaction of copper oxide with hydrochloric acid.
14	Write an ionic equation for the reaction of barium chloride solution with sodium sulphate solution.
15	Write an ionic equation for the reaction of silver nitrate solution with potassium chloride solution.
16	Write an ionic equation for the reaction of zinc with silver nitrate solution.
17	Write ionic equations for the reactions of sodium hydroxide and potassium hydroxide with hydrochloric acid.
18	Write ionic equations for the reactions of sodium hydroxide and potassium hydroxide with nitric acid.
19	Write ionic equations for the reactions of sodium hydroxide and potassium hydroxide with sulphuric acid.
20	What do you notice about the answers to questions 17, 18 and 19?

Steps for writing ionic equations.

Step 1 : Write the correct formulae of the reactants & the products.

Step II : Balance the equation.

Step III : Write the state symbols, aqueous (aq), liquid (l), gaseous (g), solid (s), vapour (v)

Step IV : Seperate ONLY the (aq) molecules in to their respective ions.

Step V : Cancel the common ions. (spectator ions)

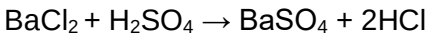
Rules for solubility of salts

1. All nitrate salts are soluble.
2. All salts of Na^+, K^+ & NH_4^+ are soluble.
3. Most Chloride salts are soluble. Exceptions : AgCl, $PbCl_2$
4. Most sulfate salts are soluble. Exceptions : $BaSO_4$, $PbSO_4$,$CaSO_4$
5. Most of hydroxide salts are slightly soluble. Important soluble hydroxides are : NaOH, KOH, & $Ca(OH)_2$
6. Most carbonate salts are insoluble. Except for Na^+, K^+ & NH_4^+

Answers

Calculations of products/reactants based on equations

1. What mass of barium sulfate would be produced from 10 g of barium chloride in the following reaction?



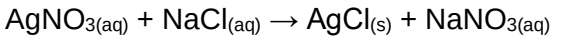
$$BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2HCl$$

2. What mass of potassium chloride would be produced from 20 g of potassium carbonate?

3. What masses of ethanol and ethanoic acid would need to be reacted together to give 1 g of ethyl ethanoate?

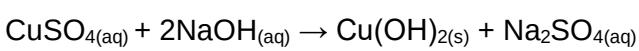
4. What mass of iron(III) oxide would need to be reduced to produce 100 tonnes of iron in a blast furnace?

5. What mass of silver nitrate as a solution in water would need to be added to 5 g of sodium chloride to ensure complete precipitation of the chloride?



$$AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$$

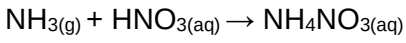
6. A solution of copper sulphate reacts with sodium hydroxide solution to produce a precipitate of copper hydroxide according to the following equation:



$$CuSO_{4(aq)} + 2NaOH_{(aq)} \rightarrow Cu(OH)_{2(s)} + Na_2SO_{4(aq)}$$

What mass of sodium hydroxide would be needed to convert 15.95 g of copper sulfate to copper hydroxide and what mass of copper hydroxide would be produced?

7. What volume of ammonia gas would be needed to produce 40 g of ammonium nitrate in the following reaction?



$$NH_{3(g)} + HNO_{3(aq)} \rightarrow NH_4NO_{3(aq)}$$

8. In the reaction between calcium carbonate and nitric acid what mass of calcium nitrate and what volume of carbon dioxide would be produced from 33.3 g of calcium carbonate?

9. What would be the total volume of gas produced by the action of heat on 33.1 g of lead(II) nitrate ?

10. .Sulfur dioxide can be removed from the waste gases of a power station by passing it through a slurry of calcium hydroxide. The equation for this reaction is:

$$SO_{2(g)} + Ca(OH)_{2(aq)} \rightarrow CaSO_{3(aq)}) + H_2O(l)$$

What mass of calcium hydroxide would be needed to deal with 1000 dm3 of Sulfur dioxide?

11. In a fermentation reaction glucose is converted to alcohol and carbon dioxide according to the following equation:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

What mass of alcohol and what volume of carbon dioxide would be produced from 10 g of glucose?

12. In the following reactions calculate the mass of precipitate formed from 20 g of the metal salt in each case.

(i) $ZnSO_{4(aq)} + 2NaOH \rightarrow Zn(OH)_{2(s)} + Na_2SO_{4(aq)}$

(ii) $Al_2(SO_4)_{3(aq)} + 6NaOH \rightarrow 2\ Al(OH)_{3(s)} + 3Na_2SO_{4(aq)}$

(iii) $MgSO_{4(aq)} + 2NaOH \rightarrow Mg(OH)_{2(s)} + Na_2SO_{4(aq)}$

13. What volume of hydrogen would be produced by 1 g of calcium in its reaction with water?

14. What mass of magnesium would be needed to produce 100 cm^3 of hydrogen?

Answers

Reactions involving gases

Whenever gases are involved in a reaction you need to remember that they have both mass and volume and that **1 mole of any gas has the same volume, 24 000 cm^3, at room temperature and 1 atmosphere pressure as 1 mole of any other gas**. (See *Section 4* for more details)

This means:

2 g of hydrogen, H_2, has a volume of 24 000 cm^3

32 g of oxygen, O_2, has a volume of 24 000 cm^3

81 g of hydrogen bromide, HBr, has a volume of 24 000 cm^3

The effect of this is to make calculations involving gas volumes much easier than you might expect.

Consider the following reaction:

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

This says:

2 moles of NO(g) react with 1 mole of O_2(g) to give 2 moles of NO_2(g)

$\therefore$ (2 x 24 000) cm^3 of NO react with (1 x 24 000) cm^3 of oxygen to give (2 x 24 000) cm^3 of NO_2

2 cm^3 of NO react with 1 cm^3 of oxygen to give 2 cm^3 of NO_2

ie for gases only the reacting volume ratios are the same as the reacting mole ratios in the equation.

Example 1

What volume of sulphur trioxide would be produced by the complete reaction of 100 cm^3 of sulphur dioxide with oxygen? What volume of oxygen would be needed to just react with the sulphur dioxide?

	$2SO_2(g)$	+	$O_2(g)$	$\rightarrow$	$2SO_3(g)$
Ratios	2		1		2
ie	1		½		1
	100 cm^3		50 cm^3		100 cm^3

Thus 100 cm^3 of sulphur dioxide will need 50 cm^3 of oxygen and produce 100 cm^3 of sulphur dioxide.

Example 2

What would be the composition of the final product in Example 1 if 100 cm^3 of oxygen had been used rather than 50 cm^3?

Since 100 cm^3 of the sulphur dioxide needs only 50 cm^3 of oxygen there must be 50 cm^3 of oxygen unused. Thus the final volume is:

100 cm^3 of sulphur dioxide plus 50 cm^3 of excess oxygen = 150 cm^3

Example 3

What volume of ammonia would be produced if 10 cm^3 of nitrogen was reacted with 20 cm^3 of hydrogen?

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

You need to think before you start this question. The reacting volumes given in the question are not the same as those in the reaction. You must have excess of one of the gases.

From the equation:

10 cm^3 of nitrogen needs 30 cm^3 of hydrogen. You only have 20 cm^3 of hydrogen so the nitrogen is in excess**.**

In this case you will need to use the hydrogen volume in the calculation.

	$N_2(g)$	+	$3H_2(g)$	$\rightarrow$	$2NH_3(g)$
Ratios	1		3		2
	1/3		1		2/3
	1/3 x 20		20		2/3 x 20
	6.67 cm^3		20 cm^3		13.33 cm^3

Thus 20 cm^3 of hydrogen will react to give **13.33 cm^3 of ammonia** and there will be 3.33 cm^3 of hydrogen left over.

Calculations based on equations involving only gases

Section a

In *Section a*. assume that you have 10 cm^3 of the first named reactant and then calculate the volumes of all the gases involved in the equation. In these examples the reactions are being carried out at above 100°C and you should assume the water is present as a gas and therefore has a volume.

1	CH_4	+	$2O_2$	$\rightarrow$	CO_2	+	$2H_2O$
2	C_2H_4	+	$3O_2$	$\rightarrow$	$2CO_2$	+	$2H_2O$
3	$2C_2H_2$	+	$5O_2$	$\rightarrow$	$4CO_2$	+	$2H_2O$
4	$2C_8H_{18}$	+	$25O_2$	$\rightarrow$	$16CO_2$	+	$18H_2O$
5	N_2	+	$3H_2$	$\rightarrow$	$2NH_3$		

Section b

In *Section b.* you are asked to find the total volume of gas produced at room temperature and pressure. You should ignore the volume of water produced as this will have condensed as a liquid. Be careful in some cases, as there is an excess of one of the reactants.

1 What volume of oxygen would be needed to convert 1000 cm^3 of nitrogen monoxide, NO, to nitrogen dioxide, NO_2? (Assume all volumes are measured at the same temperature and pressure.)

2 In the production of sulphuric acid sulphur dioxide is converted to sulphur trioxide by reaction with the oxygen in the air. What volume of air (assume 20% of the air is oxygen) would be needed to produce 150 cm^3 of sulphur trioxide? Assume complete conversion of sulphur dioxide to sulphur trioxide.

3 What is the final volume of gas produced at room temperature when 10 cm^3 of methane is burnt with 30 cm^3 of oxygen?

4 What is the final volume of gas produced at room temperature if 5 cm^3 of octane are burnt with 100 cm^3 of oxygen?

5 In a reaction between methane and oxygen 60 cm^3 of methane was burnt with 60 cm^3 of oxygen. What is the composition of the gas mixture produced?

6 What volume of ammonia would be produced if 10 cm^3 of nitrogen was reacted with 60 cm^3 of hydrogen?

7 What would be the final volume of gas produced in the reaction between 10 cm^3 of hydrogen and 10 cm^3 of oxygen?

The percentage yield

A reaction may not always yield the total amount of product predicted by the chemical equation. The loss may be due to: -

- An incomplete reaction
- Errors in weighing the reactants & products
- Loss of material due to transferring & separating the product

The percentage yield can be calculated by using the below equation.

$$\textit{Percentage yield} = \frac{\textbf{Actual yield}}{\textbf{Expected yield}} \textbf{X 100 \%}$$

Example:

Heating 12.4 g of copper (II) carbonate in a crucible produced 7.0 g of copper (II) oxide. What is the percentage yield of copper (II) oxide?

$CuCO_3 \longrightarrow CuO + CO_2$

1mol	1mol	1mol
(64+12+48)	(64+16)	
=124g	=80g	

Therefore, heating 12.4g of $CuCO_3$ should produce 8.0g of CuO

Expected yield = 8.0g
Actual yield = 7.0g

Percentage yield = $\frac{7.0}{8.0}$ x 100 % = 87.5 %

Questions

1. Reacting 216g of Iron (III) Oxide with Carbon monoxide in the blast furnace produce 140 g of Iron. What is the percentage yield of Iron?

2. Heating 66.20 g of Lead (II) nitrate produced 40 g of Lead (II) oxide. What is the percentage yield of Lead (II) oxide?

3. Heating 20 g of Calcium Carbonate in a crucible produced 10.5 g of Calcium oxide. What is the percentage yield of Calcium oxide?