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Equations and calculations

Specification references

- C3.2.2 Amounts of substances in equations (H)
- C3.2.3 Using moles to balance equations (H)
- C3.2.4 Limiting reactants (H)
- MS 1a, 1c, 3c, 3d
- WS 4.1

Aims

This activity gives you practice in using balanced equations to calculate the masses of substances that react. It also gives you practice in writing balanced equations if the masses of the reactants and products are known. Converting masses into moles is an important part of this.

Learning outcomes

After completing this activity, you should be able to:

- explain why chemical equations must be balanced
- calculate the masses of substances shown in a balanced symbol equation
- calculate the masses of reactants and products from the balanced symbol equation and the mass of a given reactant or product
- write a balanced equation given the masses of reactants and products
- identify the limiting reactant in a chemical equation
- explain the effect of a limiting quantity of a reactant on the amount of products it is possible to obtain
- use balanced equations to calculate reacting masses when there is a limiting reactant.

Setting the scene

This activity gives you practice in using balanced equations to calculate the masses of substances that react. There are three steps to this type of calculation:

- use the M_r to work out the number of moles of the substance whose mass you know (no. of moles = mass in g/M_r)
- use the balanced equation to work out the number of moles of the substance whose mass you are finding
- calculate the mass of this substance from its M_r (mass in g = M_r × no. of moles).

You can also use these ideas to write a balanced equation if the masses of reactants and products are known.

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Worked example

Sodium hydroxide reacts with chlorine gas to make bleach. This reaction happens when chlorine gas is bubbled through a solution of sodium hydroxide. The balanced symbol equation for the reaction is:

2NaOH	+	Cl_2	→	NaOCl	+	NaCl	+	H_2O
sodium hydroxide		chlorine		bleach		salt		water

If we have a solution containing 100 g of sodium hydroxide, how much chlorine gas do we need to convert it to bleach?

Solution

(A_r values: H = 1, O = 16, Na = 23 and Cl = 35.5)

Mass of 1 mole of	
NaOH	Cl_2
= 23 + 16 + 1 = 40	= 35.5 × 2 = 71

The table shows that 1 mole of sodium hydroxide has a mass of 40 g.

So 100 g of sodium hydroxide is $\frac{100}{40} = 2.5$ moles.

The balanced symbol equation tells us that for every 2 moles of sodium hydroxide we need 1 mole of chlorine to react with it.

So we need $\frac{2.5}{2} = 1.25$ moles of chlorine.

The table shows that 1 mole of chlorine has a mass of 71 g.

So we will need 1.25 × 71 = 88.75 g of chlorine to react with 100 g of sodium hydroxide.

Task

Make a flow chart to summarise the steps involved in calculating the masses of substances reacting. With a different colour, illustrate it using the worked example above.

Use your flow chart to help you answer the questions that follow.

Questions

1 When calcium carbonate is heated, it decomposes to form calcium oxide and carbon dioxide. This reaction is represented by the following equation:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

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a Calculate the M_r of $CaCO_3$ and CaO.

....

.... (*1 mark*)

b If 25 g of calcium carbonate is heated:

i calculate the number of moles of calcium carbonate used

....

.... (*1 mark*)

ii from the balanced equation, state the number of moles of calcium oxide produced

....

.... (*1 mark*)

iii calculate the mass of calcium oxide produced.

....

.... (*1 mark*)

c Calculate the M_r of CO_2 and use it to calculate the mass of CO_2 produced when 1 kg (1000 g) of $CaCO_3$ is heated.

....

.... (*1 mark*)

(A_r values: Ca = 40, O = 16, C = 12)

2 When lead dioxide is heated with hydrogen, the following reaction occurs:

$$PbO_2(s) + 2H_2(g) \rightarrow Pb(s) + 2H_2O(g)$$

a Work out the M_r of PbO_2. (*1 mark*)

b If 478 g of lead dioxide is heated calculate:

i the number of moles of lead dioxide used

....

.... (*1 mark*)

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ii the number of moles of lead produced

....

.... (*1 mark*)

iii the mass of lead produced.

....

.... (*1 mark*)

c Calculate the mass of hydrogen needed to make 20.7 g Pb.

....

....

.... (*3 marks*)

(A_r values: Pb = 207, O = 16, H = 1)

3 Sodium hydrogencarbonate decomposes on heating:

$$2\ NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$$

a If 3.36 g of sodium hydrogencarbonate is heated calculate:

i the number of moles of sodium hydrogencarbonate used

....

.... (*1 mark*)

ii the number of moles of sodium carbonate produced

....

.... (*1 mark*)

iii the mass of sodium carbonate produced.

....

.... (*1 mark*)

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b If 2.1 kg (2100 g) of sodium hydrogencarbonate is heated, calculate the mass of CO_2 produced.

....

....

.... (*3 marks*)

c Sodium hydrogen carbonate is commonly known as bicarbonate of soda. It is used in cake making to make the dough rise. Explain how it does this.

....

....

.... (*2 marks*)

(A_r values: Na = 23, C = 12, O = 16, H = 1)

4 Potassium nitrate (KNO_3) decomposes on heating to give potassium nitrite (KNO_2) and oxygen (O_2).

When 4.04 g of KNO_3 is heated, 3.40 g of KNO_2 is produced.

a Use the law of conservation of mass to work out the mass of O_2 produced.

....

.... (*1 mark*)

b Calculate the M_r values of KNO_3, KNO_2, and O_2.

....

.... (*2 marks*)

c Calculate the number of moles of

i KNO_3

....

.... (*1 mark*)

ii KNO_2

....

.... (*1 mark*)

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iii O_2.

....

.... (*1 mark*)

d Work out the simplest whole number ratio of these values and use this ratio to write a balanced equation for the reaction.

....

....

.... (*2 marks*)

e Explain why potassium nitrate is an important component in fireworks.

....

....

.... (*2 marks*)

(A_r values K = 39, N = 14, O = 16)

5 Iron(III) oxide (Fe_2O_3) is reduced by carbon on heating to give iron metal (Fe) and carbon dioxide (CO_2).

When 480 g of Fe_2O_3 is heated with carbon, 336 g of Fe and 198 g of CO_2 are produced.

a Use the law of conservation of mass to work out the mass of carbon that reacted.

....

.... (*1 mark*)

b Calculate the simplest whole number ratio of moles of Fe_2O_3, C, Fe, and CO_2.

....

....

....

....

.... (*4 marks*)

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c Write a balanced equation for the reaction.

.... (*1 mark*)

d Explain why this is an important industrial process.

....

.... (*1 mark*)

(A_r values Fe = 56, C = 12, O = 16)

Student follow up

In a chemical reaction involving two reactants, it is common to use an excess of one of the reactants to ensure that all of the other reactant is used. The reactant that is completely used up is called the limiting reactant because it limits the amount of products that can be made.

The following questions illustrate these ideas.

1 The reaction between copper oxide and carbon can be used to make copper metal.

The equation for this reaction is:

$$2CuO(s) + C(s) \rightarrow 2Cu(s) + CO_2(g)$$

A mixture of 4.0 g of CuO and 1.2 g of carbon is heated.

a Calculate the number of moles in 4.0 g of CuO.

....

.... (*1 mark*)

b Calculate the number of moles in 1.2 g of C.

....

.... (*1 mark*)

c The balanced equation tells us that for every 1 mole of carbon we need 2 moles of copper oxide. Use your answers to **a** and **b** to work out which reactant is the limiting reactant.

....

....

.... (*2 marks*)

d What mass of Cu would you expect to make?

....

....

.... (*2 marks*)

(A_r values: Cu = 64, C = 12, O = 16)

2 The reaction between zinc carbonate and hydrochloric acid can be used to make zinc chloride.

The equation for this reaction is:

$$ZnCO_3(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2O(l) + CO_2(g)$$

6.25 g of $ZnCO_3$ was added to a solution containing 1.825 g of HCl.

a Which reactant is in excess? Show your reasoning.

....

....

....

.... (*4 marks*)

b What mass of zinc chloride would you expect to make?

....

.... (*2 marks*)

(A_r values: Zn = 65, Cl = 35.5, H = 1)