GCSE · AQA · Chemistry

2 hours 21 questions

Exam Questions

Yield & Atom Economy

Percentage Yield / Theoretical Masses of Products / Calculating Atom Economy / Choosing a Reaction Pathway

Easy (6 questions)	/42
Medium (10 questions)	/36
Hard (5 questions)	/43
Total Marks	**/121**

Scan here to return to the course
or visit savemyexams.com

Easy Questions

1 (a) This question is about the yield of chemical reactions.

In practice, scientists aim for a 100% yield but this is rarely achieved.

Complete the sentences to explain why a 100% yield is not achieved.

Choose answers from the box.

purification	reversible	incomplete
transfer	side reactions	

Reactants and products can be left behind during _____ from one container to another.

_____ reactions can never have a 100% yield because the products are forming reactants.

A reaction might not go to completion because of _____ or the presence of an impurity. These reactions are described as _____ .

Answer

a) The complete sentences to explain why a 100% yield is not achieved are:

Reactants and products can be left behind during transfer from one container to another.

Reversible reactions can never have a 100% yield because the products are forming reactants.

A reaction might not go to completion because of side reactions or the presence of an impurity. These reactions are described as incomplete.

- Transfer; [1 mark]
- Reversible; [1 mark]

- Side reactions; [1 mark]
- Incomplete; [1 mark]
  Answers must be in the order shown

[Total: 4 marks]

- If you are not sure for questions like these, try reading it in your head as certain words are more / less suitable for certain gaps
  - e.g. A reaction might not go to completion because of _____ or the presence of an impurity
  - The best fit answer for this gap is probably side reactions
  - Other answers such as reversible or incomplete do not work in this space

(4 marks)

(b) There are different types of yield.

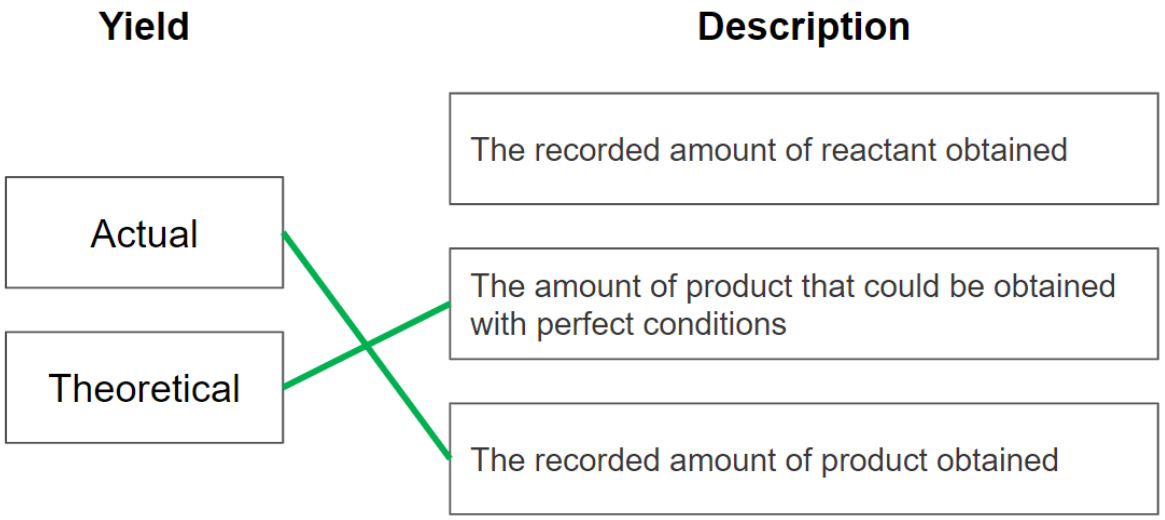
The percentage yield compares the actual yield to the theoretical yield.

Draw **one** line from each yield to its description.

Yield	Description
Actual	The recorded amount of reactant obtained
Theoretical	The amount of product that could be obtained with perfect conditions
	The recorded amount of product obtained

Answer

The correct pairs are:



- Correctly matches actual with the recorded amount of product obtained: [1 mark]
- Correctly matches theoretical with the amount of product that could be obtained with perfect conditions: [1 mark]

[Total: 2 marks]

- **Careful:** Yield is all about the amount of product that is formed
  - Actual is the amount of product that you do get
  - Theoretical is the amount of product that you could get

(2 marks)

(c) What is the correct equation to calculate percentage yield?

Circle **one** equation.

$\frac{\text{actual yield}}{\text{theoretical yield}}$	$\frac{\text{actual yield}}{\text{theoretical yield}} \times 100$	$\frac{\text{theoretical yield}}{\text{actual yield}} \times 100$

Answer

The correct equation to calculate percentage yield is:

- $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100$; [1mark]

[Total: 1 mark]

- Don't forget to be a percentage you should multiply by 100

(1 mark)

2 (a) A student completed an experiment using magnesium to displace copper from copper(II) sulfate.

Complete the symbol equation.

$$Mg + CuSO_4 \rightarrow \_\_\_\_\_ + \_\_\_\_\_$$

Answer

The completed symbol equation is:

$$Mg + CuSO_4 \rightarrow Cu + MgSO_4$$

- Cu
  AND
  $MgSO_4$; [1 mark]
  Both chemicals are required for the mark

[Total: 1 mark]

- Magnesium is a Group 2 metal
  - The magnesium has a 2+ charge when it is in magnesium sulfate
  - Mg^{2+}
- The copper in copper(II) sulfate is behaving as a Group 2 metal
  - The roman numerals tell you that copper has a 2+ charge when it is in copper(II) sulfate
  - Cu^{2+}
- This means that the magnesium and copper will just swap places

(1 mark)

(b) The student added 4.8 g of magnesium to a solution of copper(II) sulfate.

Calculate the number of moles of magnesium that the student used.

Relative atomic mass (A_r): Mg = 24

Use the equation:

$$\text{moles} = \frac{\text{mass}}{M_r}$$

Answer

To calculate the number of moles of magnesium that the student used:

- $\text{Moles} = \frac{\text{mass}}{M_r} = \frac{4.8}{24}$ = 0.2 moles; [1 mark]

[Total: 1 mark]

- Calculating moles is often the first step in a longer percentage yield calculation as you have to determine the theoretical yield from the information that you are given

(1 mark)

(c) Using your answer to part (b), calculate the theoretical yield of copper.

Relative atomic mass (A_r): Cu = 63.5

Theoretical yield of copper = _____ *g*

Answer

To calculate the theoretical yield of copper:

- Maximum number of moles of copper = 0.2 moles; [1 mark] *The previous answer to part (b) can be used for this mark*
- Maximum mass of copper = moles x M_r = 0.2 x 63.5 = 12.7 g; [1 mark]
  This calculation should use your answer to part (b) in the calculation (error carried forward / transferred error)

[Total: 2 marks]

- From the equation in part (a), one mole of magnesium displaces one mole of copper out of copper(II) sulfate
- This means that 0.2 moles of magnesium will displace 0.2 moles of copper out of copper(II) sulfate

(2 marks)

(d) Another student completes the same experiment using 4.8 g of magnesium.

They obtain 10.16 g of copper.

What is the percentage yield of this student's experiment?

Answer

The percentage yield of the student's experiment is:

- Percentage yield = $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{10.16}{12.7} \times 100$; [1 mark]
- Percentage yield = 80%; [1 mark]

[Total: 2 marks]

- If you are not given the equation, then you should:
    1. Write down the equation that you are going to use
    2. Substitute the values into the equation
    3. Write down the final answer
- Following these steps helps show your working in a clear way for the examiner
    - This means that if you make a mistake the examiner can identify the single mistake and potentially only take one mark
    - Without any working, the examiner will have to take all the marks if you get the wrong answer
- The most common mistake in percentage yield calculations is to have the two numbers the wrong way up which gives over 100%
    - **Remember:** A percentage yield of over 100% is not possible

(2 marks)

3 (a) This question is about atom economy.

What does atom economy measure?

Answer

Atom economy measures:

- The efficiency of a chemical reaction
  OR
  How much of the reactants are turned into useful products; [1 mark]

[Total: 1 mark]

(1 mark)

(b) Silver nitrate and sodium iodide can react to form silver iodide.

The equation for the reaction is:

$$AgNO_3\ (aq) + NaI\ (aq) \rightarrow AgI\ (s) + NaNO_3\ (aq)$$

A student looks at the useful silver iodide product of this reaction and concludes that the percentage atom economy is 50%.

How might the student **mistakenly** arrive at this conclusion?

Answer

The student might **mistakenly** arrive at a conclusion of 50% atom economy because:

- Silver iodide is one of the two products formed; [1 mark]
- $\frac{1}{2} \times 100$ = 50%
  OR
  Which is 50%; [1 mark]

[Total: 2 marks]

- **Careful:** Atom economy **cannot** be calculated without calculating the masses of the products – the useful / desired product and the by-products
- There are actually two possible equations that you can use, although they are essentially the same equation

- Percentage atom economy = $\frac{\text{relative formula mass of desired product}}{\text{sum of relative formula masses of all reactants}}$
- Percentage atom economy = $\frac{\text{relative formula mass of desired product}}{\text{sum of relative formula masses of all products}}$
- You will see both equations used in different textbooks, revision guides, etc

(2 marks)

(c) Calculate the relative formula mass of silver iodide, AgI.

Relative atomic masses (A_r): Ag = 108; I = 127

Answer

The relative formula mass of silver iodide is:

- 108 + 127 = 235; [1 mark]

[Total: 1 mark]

(1 mark)

(d) Calculate the relative formula mass of sodium nitrate, $NaNO_3$.

Relative atomic masses (A_r): N = 14; Na = 23; O = 16

Answer

The relative formula mass of sodium nitrate, $NaNO_3$ is:

- 23 + 14 + (3 x 16); [1 mark]
- 85; [1mark]

[Total: 2 marks]

(2 marks)

(e) Calculate the percentage atom economy for making silver iodide.

Use the equation:

$$\text{Percentage atom economy} = \frac{\text{relative formula mass of desired product}}{\text{total mass of all products}} \times 100$$

Give your answer to 3 significant figures.

Answer

To calculate the percentage atom economy for making silver iodide:

- Percentage atom economy = $\frac{235}{235 + 85} \times 100$; [1 mark]
- Percentage atom economy = 73.4375%; [1 mark]
- Percentage atom economy = 73.4%; [1 mark]

[Total: 3 marks]

- **Careful:** The specification gives you one version of the atom economy equation but this question asks you to use the other form
  - **Specification:** Percentage atom economy = $\frac{\text{relative formula mass of desired product}}{\text{total mass of all reactants}}$
  - **This question:** Percentage atom economy = $\frac{\text{relative formula mass of desired product}}{\text{total mass of all products}}$
- If you are asked to give your answer to 3 significant figures, then you must do it
  - It may not always be worth a mark on a mark scheme but failing to put an answer to 3 significant figures will definitely not achieve full marks

(3 marks)

4 (a) Copper sulfate can be made by reacting copper oxide with sulfuric acid.

$$CuO + H_2SO_4 \longrightarrow CuSO_4 + H_2O$$

Calculate the percentage atom economy for making copper sulfate.

Use the equation:

$$\text{Percentage atom economy} = \frac{\text{relative formula mass of desired product}}{\text{total mass of all reactants}} \times 100$$

Relative formula masses (M_r): $H_2SO_4 = 98$; $CuO = 79.5$; $CuSO_4 = 159.5$

Give your answer to 3 significant figures.

Answer

To calculate the percentage atom economy for making copper sulfate:

- Percentage atom economy = $\frac{159.5}{79.5 + 98} \times 100$; [1 mark]
- Percentage atom economy = 89.859...%; [1 mark]
- Percentage atom economy = 89.9%; [1 mark]

[Total: 3 marks]

- This equation asks you to divide by the total mass of all reactants
- This means that one mark will be for showing that you are using the mass of the reactants

(3 marks)

(b) Reacting copper carbonate, $CuCO_3$, with sulfuric acid forms copper sulfate and two other products.

$$CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$$

What type of reaction is this?

Tick (✓) **one** box.

Combustion	
Endothermic	
Neutralisation	
Decomposition	

Answer

The type of reaction is:

Combustion	
Endothermic	
Neutralisation	✓; [1 mark]
Decomposition	

[Total: 1 mark]

- This is the reaction between an acid and a base, which is neutralisation
- A salt and water are formed (as well as carbon dioxide), which can be another indication of a neutralisation reaction

(1 mark)

(c) The two methods of forming copper(II) sulfate using sulfuric acid are:

Method 1: $CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$

Method 2: $CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$

Which method has the highest atom economy? Explain your answer.

Method: _____

Explanation: _____

Answer

The method with the highest atom economy is:

- Method 1; [1 mark]
- (Because) method 1 only produces one other product
  OR
  (Because) method 2 produces two other / more products; [1 mark]

[Total: 2 marks]

- Atom economy can also be determined by looking carefully at the number of products
  - In this question, method 1 produces the desired product and **one** other by-product while method 2 produces the desired product and **two** other by-products
    - Therefore, method 2 produces more by-products and has a lower atom economy
  - In other questions, you might find that the products are the desired product and **one** other by-product
    - In these cases, you should look at the number of moles of by-product – the reaction that produces more moles of by-product will have the lower atom economy
  - If it is not obvious, you can always calculate the percentage atom economy to prove which method has the lower atom economy

(2 marks)

(d) High atom economy is a desirable attribute in industrial chemical processes.

Place the following attributes of chemical reactions into the correct columns in **Table 1**.

- Produce useful byproducts
- High percentage yield
- High energy costs
- Efficient reactions
- Use expensive raw materials

Table 1

Desirable attribute	Undesirable attribute

Answer

The correctly sorted attributes are:

Desirable attribute	Undesirable attribute
Produce useful byproducts; [1 mark]	High energy costs; [1 mark]
High percentage yield; [1 mark]	Expensive raw materials; [1 mark]
Efficient reactions; [1 mark]	

[Total: 5 marks]

(5 marks)

5 (a) To produce a sample of hex-1-ene, 10.2 g of hexan-1-ol is dehydrated by heating with an excess of phosphoric(V) acid.

Hexan-1-ol → Hex-1-ene + water

$C_6H_{13}OH \rightarrow C_6H_{12} + H_2O$

After purification, 5.04 g of hex-1-ene was produced.

Calculate the number of moles of hexan-1-ol.

Relative molecular masses (M_r): $C_6H_{13}OH$ = 102; C_6H_{12} = 84

Answer

To calculate the number of moles of hexan-1-ol and hex-1-ene:

- Moles of hexan-1-ol = $= \frac{\text{mass}}{M_r} = \frac{10.2}{102}$ = 0.1 moles; [1 mark]

[Total: 1 mark]

- **Remember:** Moles = $\frac{\text{mass}}{M_r}$

(1 mark)

(b) Calculate the mass of hex-1-ene that could be produced.

Answer

The mass of hex-1-ene that could be produced is:

- Moles of hex-1-ene = 0.1 moles; [1 mark]
  Your answer from part (a) is accepted and can be used in this answer to gain the marks
  The idea that 0.1 moles of hexan-1-ol forms 0.1 moles of hex-1-ene needs or that there is a 1: 1 relationship needs to be seen

- Mass = moles x M_r = 0.1 x 84 = 8.4 g; [1 mark]

[Total: 2 marks]

- When calculating reacting masses answers, you should aim to clearly state the relationship between the number of moles of reactant and the number of moles of product
  - This is because there will be times when it is not 1 : 1 and will therefore impact your final answer

(2 marks)

(c) What is the percentage yield for the production of hex-1-ene from hexan-1-ol in this experiment?

Answer

The percentage yield for the production of hex-1-ene from hexan-1-ol in this experiment is:

- Percentage yield $= \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{5.04}{8.4} \times 100$; [1 mark]

- Percentage yield = 60%; [1 mark]

[Total: 2 marks]

- **Remember:** Percentage yield $= \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$

(2 marks)

(d) What is the percentage atom economy for the production of hex-1-ene from hexan-1-ol in this experiment?

$$C_6H_{13}OH \rightarrow C_6H_{12} + H_2O$$

Relative molecular masses (M_r): C_6H_{12} = 84; H_2O = 18

Give your answer to three significant figures.

Answer

The percentage atom economy for the production of hex-1-ene from hexan-1-ol in this experiment is:

- Percentage atom economy $= \frac{mass\ of\ desired\ product}{total\ mass\ of\ all\ products} \times 100 = \frac{84}{(84+18)} \times 100$; [1 mark]
- Percentage atom economy = 82.3529...%; [1 mark]
- Percentage atom economy = 82.4%; [1 mark]

[Total: 3 marks]

- Percentage yield and percentage atom economy are two different calculations and it will be very rare for them to have the same value
    - Part (c) gave a 60% yield while part (d) gave an 82.4% atom economy

(3 marks)

6 Which of these is/are a factor(s) in choosing a reaction pathway?

	Atom economy	Percentage yield	Rate of reaction
A	✔		
B	✔	✔	
C		✔	✔
D	✔	✔	✔

Answer

The correct answer is D because:

- All three factors can influence the choice of a particular reaction pathway
- There are many factors including:
    - The amount of waste produced
    - The cost and availability of raw materials
    - The efficiency of the reaction
    - The position of equilibrium
    - The energy demands of the process
    - The toxicity of the materials
    - The value and usability of by-products

(1 mark)

Medium Questions

1 (a) Nickel oxide is reduced by heating with carbon, producing nickel metal and carbon monoxide.

The equation for the reaction is as follows:

$$NiO + C \longrightarrow Ni + CO$$

Calculate the percentage atom economy for the production of nickel.

Relative atomic masses (A_r): C = 12; Ni = 59

Relative formula mass (M_r): NiO = 75; CO = 28

Give your answer correct to 3 significant figures.

Percentage atom economy = _____ %

Answer

To calculate the percentage atom economy for the production of nickel:

- Total M_r of the reactants = 87; [1 mark]
- Percentage atom economy = $\frac{59}{87} \times 100$; [1 mark]
- Percentage atom economy = 67.8%; [1 mark]
  Answers of 67.8160919%, 68% or 67.82% can only be awarded 2 marks

[Total: 3 marks]

- **Remember:** Percentage atom economy = $\frac{\text{mass of desired product}}{\text{total mass of reactants (or products)}} \times 100$
- **Careful:** This question states that you should give your answer to 3 significant figures, which means that you will probably miss / lose a mark if you don't

(3 marks)

(b) Magnesium can be produced by reacting magnesium oxide with silicon.

The equation for the reaction is as follows:

$$Si\ (s) + 2MgO\ (s) \rightarrow SiO_2\ (s) + 2Mg\ (s)$$

A company calculated, based on the amount of reactants and the balanced equation, that they would produce 1.2 tonnes of magnesium, but only 0.9 tonnes was made.

Calculate the percentage yield of magnesium.

Percentage yield = _____ %

Answer

To calculate the percentage yield of magnesium:

- Percentage yield = $\frac{0.9}{1.2} \times 100$ = 75%; [1 mark]

[Total: 1 mark]

- **Remember:** Percentage yield = $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100$

- If you get a percentage above 100%, you have gone wrong somewhere and the most likely reason is that the two numbers are the wrong way up

(1 mark)

(c) State **two** reasons why the calculated yield of magnesium might not be obtained.

Answer

Two reasons why the calculated yield of magnesium might not be obtained are:

Any **two** from:

- The reaction is incomplete; [1 mark]
- Some product is lost / escaped / released during separation; [1 mark]
- Some of the reactant may react in different ways from the expected reaction; [1 mark]
- There may be impure reactant(s); [1 mark]
  Ignore measurement and calculation errors

[Total: 2 marks]

- The most common correct answers for this question are incomplete reaction and loss of product

(2 marks)

2 (a) The extraction of titanium from titanium dioxide is carried out in a two-stage industrial process:

Stage 1 $TiO_2 + 2C + 2Cl_2 \longrightarrow TiCl_4 + 2CO$

Stage 2 $TiCl_4 + 4Na \longrightarrow Ti + 4NaCl$

In the **stage 2** reaction the percentage yield obtained by a company was 91.2%

The maximum theoretical mass of titanium for this batch was 12.5 kg.

Calculate the actual mass of titanium produced.

Mass of titanium = _____ kg

Answer

The actual mass of titanium produced is:

- $12.5 \times \frac{91.2}{100}$; [1 mark]
- 11.4 kg; [1 mark]

[Total: 2 marks]

- The question tells you that the reaction has a yield of 91.2%
- Therefore, you have to calculate 91.2% of 12.5 kg

(2 marks)

(b) Copper carbonate and sulfuric acid react as follows:

$$CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$$

Relative formula masses: $CuCO_3 = 123.5$; $H_2SO_4 = 98.0$; $CuSO_4 = 159.5$

Calculate the percentage atom economy for producing copper sulfate from copper carbonate.

Atom economy = _____ %

Answer

To calculate the percentage atom economy for producing copper sulfate from copper carbonate:

- The total mass of reactants = 123.5 + 98.0 = 221.5; [1 mark]
- Percentage atom economy = $\frac{159.5}{221.5} \times 100$; [1 mark]
- Percentage atom economy = 72%; [1 mark]

[Total: 3 marks]

- **Remember:** Percentage atom economy = $\frac{\text{mass of desired product}}{\text{total mass of reactants (or products)}} \times 100$

(3 marks)

(c) Give **two** reasons why it is beneficial for the percentage atom economy of a reaction to be as high as possible.

Answer

Two reasons why it is beneficial for the percentage atom economy of a reaction to be as high as possible are:

Any **two** from:

- Important for reasons of sustainable development; [1 mark]
- Economic reasons / better profit; [1 mark]
- Waste products may be pollutants or greenhouse gases; [1 mark]

[Total: 2 marks]

(2 marks)

3 A student wanted to make 15.0 g of zinc chloride. The equation for the reaction is:

$$ZnCO_3 + 2HCl \rightarrow ZnCl_2 + CO_2 + H_2O$$

What mass of zinc carbonate should the student add to the hydrochloric acid to make 15.0 g of zinc chloride?

Relative atomic masses (A_r): C = 12 Zn = 65 O= 16 Cl = 35.5 H= 1

A. 11.0 g

B. 13.8 g

C. 15.0 g

D. 22.0 g

Answer

The correct answer is B because:

- **Step 1:** Calculate the relative formula masses of the zinc chloride and zinc carbonate:

M_r of $ZnCl_2$ = 65 + (2 x 35.5) = 136

M_r of $ZnCO_3$ = 65 + 12+ (3 x 16) = 125

- **Step 2:** Calculate the number of moles of the desired product, zinc chloride:

$$\text{moles} = \frac{\text{mass}}{\text{molar mass}} = \frac{15.0}{136} = 0.11 \text{ mol}$$

- **Step 3:** Use the balanced equation to deduce the number of moles of zinc carbonate needed:

$ZnCO_3 + 2HCl \rightarrow ZnCl_2 + CO_2 + H_2O$

0.11 mol 0.11 mol

- **Step 4:** Calculate the mass of zinc carbonate needed:

mass of $ZnCO_3$ = moles x molar mass

mass of $ZnCO_3$ = 0.11 x 125 = **13.8 g**

(1 mark)

4 A student made zinc chloride by reacting 15.0 g of zinc carbonate with hydrochloric acid.

$$ZnCO_3 + 2HCl \rightarrow ZnCl_2 + CO_2 + H_2O$$

The percentage yield of zinc chloride was 82.4%.

Calculate the mass of zinc chloride the student actually produced.

Relative atomic masses (A_r): C = 12 Zn = 65 O= 16 Cl = 35.5 H= 1

A. 13.4 g

B. 15.0 g

C. 16.3 g

D. 12.4 g

Answer

The correct answer is A because:

- **Step 1:** Calculate the relative formula masses of the zinc carbonate and zinc chloride :

M_r of $ZnCO_3$ = 65 + 12+ (3 x 16) = 125

M_r of $ZnCl_2$ = 65 + (2 x 35.5) = 136

- **Step 2:** Calculate the number of moles of the reactant, zinc carbonate:

$$\text{moles of } ZnCO_3 = \frac{\text{mass}}{\text{molar mass}} = \frac{15.0}{125} = 0.12 \text{ mol}$$

- **Step 3:** Use the balanced equation to deduce the theoretical yield of zinc chloride:

$ZnCO_3 + 2HCl \rightarrow ZnCl_2 + CO_2 + H_2O$

0.12 mol 0.12 mol

- **Step 4:** Calculate the actual yield of zinc chloride

$$\text{amount of } ZnCl_2 = \frac{0.12 \times 82.4}{100} = 0.0989$$

- **Step 5:** Calculate the mass of zinc chloride produced:

mass of $ZnCl_2$ = moles x molar mass

mass of $ZnCl_2$ = 0.0989 x 136 = **13.4 g**

(1 mark)

5 (a) In the Haber process, nitrogen and hydrogen are reacted together in conditions of high pressure and temperature to produce ammonia.

The equation for the reaction is as follows:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Calculate the percentage atom economy for the production of ammonia.

Relative formula masses (M_r): N_2 = 28; H_2 = 2; NH_3= 17

Percentage atom economy = _____ %

Answer

To calculate the percentage atom economy for the production of ammonia:

- Percentage atom economy = $\frac{(2 \times 17)}{28 + (3 \times 2)} \times 100$; [1 mark]
- Percentage atom economy = 100%; [1 mark]

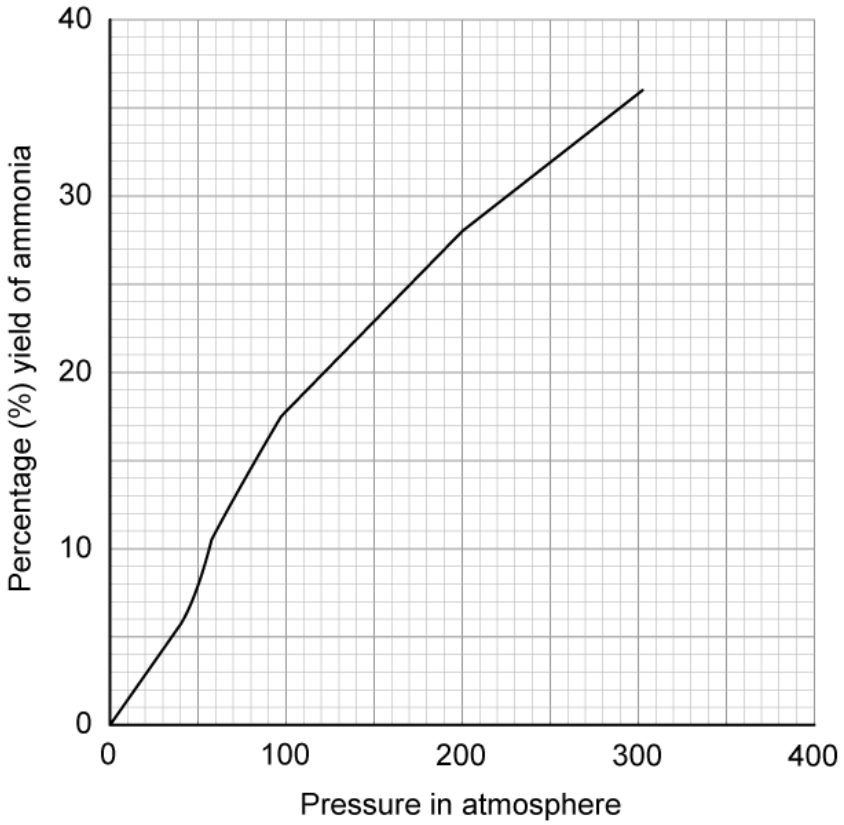
[Total: 2 marks]

- For atom economy calculations you must multiply the respective quantities by the reaction coefficients.
- If there is only one product then the atom economy must be 100%

(2 marks)

(b) **Figure 1** shows how the percentage yield of ammonia varies with changing conditions of pressure.

Figure 1



Describe the trend shown in **Figure 1**.

Answer

The trend shown in **Figure 1** is:

- As the pressure increases; [1 mark]
- The percentage yield increases; [1 mark]

[Total: 2 marks]

- **Tip:** When you are asked to describe trends, you should start your answer with the word **AS** because it makes you compare and talk about the different factors

(2 marks)

(c) Use **Figure 1** to determine the difference in percentage yield at 100 atmospheres pressure and at 250 atmospheres pressure.

Difference % yield NH_3 = _____ %

Answer

The difference in yield is:

- 32 - 18; [1 mark] *Both readings must be correct for this mark*
- 14%; [1 mark]

[Total: 2 marks]

- Read off the graph at 100 and 250 atmospheres pressure and calculate the difference between the percentages

(2 marks)

6 (a) A scientist makes zinc iodide by reacting zinc with iodine.

The equation for the reaction is:

$$Zn + I_2 \rightarrow ZnI_2$$

Relative atomic masses (M_r): Zn = 65; I = 127

14.5 g of zinc iodide is produced in the reaction.

The percentage yield obtained is 93.0%.

What is the maximum theoretical mass of ZnI_2 produced in this reaction?

Maximum theoretical mass = _____ g

Answer

The maximum theoretical mass of ZnI_2 produced in this reaction is:

$$\text{Percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

- $93.0 = \frac{14.5}{\text{maximum mass}} \times 100$; [1 mark]
- $\text{Maximum mass} = \frac{14.5}{93.0} \times 100$; [1 mark]
- Maximum mass = 15.6 (g); [1 mark]

[Total: 3 marks]

(3 marks)

(b) Suggest a reason why the percentage yield is **not** 100%.

Answer

The percentage yield is **not** 100% because:

- Some product may be lost in separation stages
  OR
  The reaction may not go to completion; [1 mark]

[Total: 1 mark]

(1 mark)

7 An equation for the reaction between copper(II) oxide and carbon is:

$$2CuO + C \rightarrow 2Cu + CO_2$$

What is the percentage atom economy for the reaction to produce copper metal?

Relative atomic masses (A_r): C = 12 Cu = 64

Relative formula mass (M_r): CuO = 80

A. 64%

B. 59.3%

C. 74.4%

D. 92%

Answer

The correct answer is C because:

- Atom economy is found using the following equation

$$\text{atom economy} = \frac{\text{sum of } M_r \text{ of the desired product}}{\text{sum of } M_r \text{ of all reactants from equation}} \times 100$$

- **Step 1**: Calculate the Mr for each reactant

M_r of CuO = 64 + 16 = 80

A_r of C = 12

- **Step 2:** Calculate the atom economy using the values from Step 1, taking into account the stoichiometry from the equation:

$$\text{atom economy} = \frac{(2 \times 64)}{(2 \times 80) + 12} \times 100 = 74.4\ \%$$

(1 mark)

8 Which of the following does **not** explain why the yield of a reaction may not be 100%?

A. The reaction may not go to completion because it is reversible

B. Some of the product may be lost when it is separated from the reaction mixture

C. Some of the reactants may react in ways different to the expected reaction

D. The reaction is endothermic and requires too much energy to complete it

Answer

The correct answer is D because:

- The yield depends on the nature of the reaction and the conditions and not on the overall energy changes
- Exothermic or endothermic reactions can go to completion and give a 100% yield

(1 mark)

9 Calcium oxide can be produced by heating calcium carbonate in a rotating kiln.

$$CaCO_3 \rightarrow CaO + CO_2$$

If 120 tonnes of calcium carbonate is heated in the kiln and 53 tonnes of calcium oxide are produced, what is the percentage yield?

Relative atomic masses (A_r): Ca = 40 C = 12 O= 16

A. 53.7%

B. 62.1%

C. 78.9%

D. 84.3%

Answer

The correct answer is C because:

- **Step 1:** Work out the relative formula masses of the reactants and products

Mr of $CaCO_3$ = 40 + 12 + (3 x 16) = 100

M_r of CaO = 40 + 16 = 56

- **Step 2:** Use the balanced equation to deduce the maximum mass of product possible

$CaCO_3 \rightarrow CaO + CO_2$

100 tonnes 56 tonnes

120 tonnes $\frac{56}{100} \times 120$ = 67.2 tonnes

- **Step 3:** Percentage yield is calculated using the following formula

$$\text{percentage yield} = \frac{\text{actual mass of product}}{\text{maximum mass of product possible}} \times 100$$

$$\text{percentage yield} = \frac{53}{67.2} \times 100 = 78.9\ \%$$

(1 mark)

10 (a) This question is about the salt zinc sulfate.

Zinc sulfate is a compound used as a dietary supplement to treat zinc deficiency.

It is also added to fertilisers, animal feeds and toothpaste. It can be made by two methods.

The equations for the two methods are as follows:

Method 1: $ZnO + H_2SO_4 \rightarrow ZnSO_4 + H_2O$

Method 2: $ZnCO_3 + H_2SO_4 \rightarrow ZnSO_4 + H_2O + CO_2$

Calculate the percentage atom economy for making $ZnSO_4$ in **Method 1** giving your answer to 3 significant figures.

Relative formula masses (*Mr*): ZnO = 81; H_2SO_4 = 98; $ZnSO_4$ = 161; $ZnCO_3$ = 125

Percentage atom economy = _____ %

Answer

The percentage atom economy for making $ZnSO_4$ in **Method 1** is:

- Percentage atom economy = $\frac{161}{(81+98)} \times 100$

  OR

  Percentage atom economy = $\frac{161}{(161+18)} \times 100$

  OR

  Percentage atom economy = $\frac{161}{(179)} \times 100$; [1 mark]

- Percentage atom economy = 89.944134; [1 mark]

- Percentage atom economy = 89.9%; [1 mark]
  An answer of 89.9% without working scores 3 marks

[Total: 3 marks]

- **Remember:** Percentage atom economy = $\frac{\text{mass of desired product}}{\text{total mass of reactants (or products)}} \times 100$

- **Careful:** This question states that you should give your answer to 3 significant figures, which means that you will probably miss / lose a mark if you don't

(3 marks)

(b) Compare the atom economy of both methods and decide which method is the most desirable.

Answer

To compare the atom economy of both methods:

- Method 2 percentage atom economy = $\frac{161}{(125+98)} \times 100$; [1 mark]

- Method 2 percentage atom economy = 72.197309; [1 mark]

- Method 2 percentage atom economy = 72.2%; [1 mark]

- Method 1 is the most favorable reaction; [1 mark]
- Because it has a higher atom economy; [1 mark]

[Total: 5 marks]

- The best way to compare atom economies when given M_r data is to complete the percentage atom economy calculations
- It is possible to use the equations and say that method 1 is more favourable because there is not as much waste lost as method 2
    - Method 1 only loses water
    - Method 2 loses water and carbon dioxide
    - However, exam technique should tell you that this is not worth 5 marks

(5 marks)

Hard Questions

1 (a) Iron is extracted from iron oxide in the blast furnace as shown.

$$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$$

1 tonne of iron oxide was reacted with carbon to produce 650 kg of molten iron.

Calculate the percentage yield for this reaction.

Relative atomic masses (A_r): Fe = 56, O = 16, C = 12

Answer

To calculate the percentage yield for this reaction:

- Moles of iron oxide = $\frac{1000000}{((2 \times 56) + (3 \times 16))}$ = 6250 moles; [1 mark]
- Moles of iron = 6250 x 2 = 12500 moles; [1 mark]
- Mass of iron = $\frac{12500 \times 56}{1000}$ = 700 kg; [1 mark]
- Percentage yield = $\frac{650}{700} \times 100$; [1 mark]
- Percentage yield = 92.9%; [1 mark]

[Total: 5 marks]

- 5 marks calculations often have two aspects to the question, in this case:
    1. Calculating the theoretical mass of iron produced from 1 tonne of iron oxide
    2. The percentage yield calculation
- **Careful:** Although a mixture of units is given in the question, you need to be working in g for the moles calculations

(5 marks)

(b) The temperature inside the blast furnace is so high that carbon monoxide can be used to extract iron instead of carbon.

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

Explain which reactant is oxidised in this reaction.

Answer

The reactant which is oxidised in this reaction is:

- Carbon monoxide **AND** because it has gained oxygen
  OR
  Carbon monoxide **AND** because the iron oxide has lost oxygen; [1 mark]

[Total: 1 mark]

- The exam command word **explain** means that a reason is required for this answer
- Since the question is only for one mark, it will not be enough to guess at one of the reactants – you will have to get the correct reactant and reason

(1 mark)

(c) Determine if the reaction of iron oxide with carbon has a higher atom economy than the reaction of iron oxide with carbon monoxide.

Relative atomic masses (Ar): Fe = 56, O = 16, C = 12

Answer

To determine if the reaction of iron oxide with carbon has a higher atom economy than the reaction of iron oxide with carbon monoxide:

- Atom economy of carbon reaction: $\frac{(4 \times 56)}{((4 \times 56) + (3 \times 44))} \times 100$ = 62.9%; [1 mark]
- Atom economy of carbon monoxide reaction: $\frac{(2 \times 56)}{((2 \times 56) + (3 \times 44))} \times 100$ = 45.9%; [1 mark]
- Therefore, the reaction with carbon has a higher atom economy; [1 mark]
  *The answer for this mark **must** agree with the percentages that are calculated*

[Total: 3 marks]

- **Remember:** Percentage atom economy = $\frac{\text{total } M_r \text{ of desired product}}{\text{total } M_r \text{ of all products}} \times 100$

(3 marks)

2 (a) This question is about magnesium sulfate.

Calculate, to three significant figures, the percentage by mass of oxygen in magnesium sulfate.

Relative atomic masses (A_r): Mg = 24, S = 32, O = 16

Answer

To calculate the percentage by mass of oxygen in magnesium sulfate:

- Relative molar mass of $MgSO_4$ = 24 + 32 + (4 x 16) = 120; [1 mark]
- Percentage by mass = $\frac{4 \times 16}{120} \times 100 = 53.3\%$; [1 mark]
  *The answer **must** be given to three significant figures for the mark*

[Total: 2 marks]

- Sulfate is one of the ions that you can be expected to know, SO_4^{2-}
- **Careful:** There are four oxygen atoms in magnesium sulfate so you have to calculate the percentage by mass for all four oxygens
- The question says to give your answer to three significant figures which mean that you will probably lose a mark if you don't give your final answer to three significant figures
  - Often giving the answer to three significant figures will be a complete mark on its own
  - Sometimes, like this question, the three significant figures is included with the mark for the final value

(2 marks)

(b) Magnesium sulfate can be produced by reacting magnesium with sulfuric acid.

$$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$$

Write **two** balanced symbol equations, including state symbols, to show how magnesium sulfate can be produced by neutralisation reactions.

Answer

Two balanced symbol equations, including state symbols, to show how magnesium sulfate can be produced by neutralisation reactions are:

- All state symbols correct in both equations; [1 mark]

Any **two** equations from:

- $MgO\ (s) + H_2SO_4\ (aq) \rightarrow MgSO_4\ (aq) + H_2O\ (l)$
    - MgO as reactant
      AND
      H_2O as product; [1 mark]
- $Mg(OH)_2\ (s) + H_2SO_4\ (aq) \rightarrow MgSO_4\ (aq) + 2H_2O\ (l)$
    - $Mg(OH)_2$ as reactant
      AND
      $2H_2O$ as product; [1 mark]
- $MgCO_3\ (s) + H_2SO_4\ (aq) \rightarrow MgSO_4\ (aq) + H_2O\ (l) + CO_2\ (g)$
    - $MgCO_3$ as reactant
      AND
      H_2O and CO_2 as products; [1 mark]

[Total: 3 marks]

- The question guides you to reactions forming water as it asks for neutralisation reactions
- These will require a base and sulfuric acid
    - Bases include metal oxides, metal hydroxides and metal carbonates

(3 marks)

(c) Calculate the atom economy for the formation of magnesium sulfate by the reaction of magnesium and sulfuric acid.

Relative atomic masses (A_r): Mg = 24 S = 32 O = 16

Answer

To calculate the atom economy for the formation of magnesium sulfate by the reaction of magnesium and sulfuric acid.

- M_r of $MgSO_4$ = 24 + 32 + (4 x 16) = 120
  AND
  Percentage atom economy = $\frac{120}{(120+2)} \times 100$; [1 mark]

- 98.4%; [1 mark]
  An answer of 98.3606557377(%) correctly rounded to at least 2 significant figures scores 2 marks

[Total: 2 marks]

- **Remember:** Percentage atom economy = $\frac{\text{total } M_r \text{ of desired product}}{\text{total } M_r \text{ of all products}} \times 100$

(2 marks)

(d) Explain why the reaction of magnesium with sulfuric acid has a larger atom economy compared to the reactions in part (b).

Answer

The reaction of magnesium with sulfuric acid has a larger atom economy compared to the reactions in part (b) because:

- Atom economy analyses the efficiency of the reaction; [1 mark]

- Magnesium with sulfuric acid produces only hydrogen as a by-product
  OR
  Reactions of other magnesium compounds with sulfuric acid produces more by-products / by-products with a larger mass; [1 mark]

[Total: 2 marks]

- Atom economy measures/analyses the efficiency of a chemical reaction
- The reaction of magnesium with sulfuric acid only produces hydrogen as a by-product / waste product
    - Hydrogen has a molecular mass of 2
    - This gives an atom economy of 98.4%
- The reaction of magnesium oxide with sulfuric acid produces water as a by-product / waste product
    - This atom economy is lower than magnesium because the by-product is water, which has a higher mass than hydrogen
    - Water has a molecular mass of 18
    - This gives an atom economy of $\frac{120}{(120 + 18)} \times 100 = 87.0\%$
- The reaction of magnesium hydroxide with sulfuric acid produces two waters as by-products / waste products
    - This atom economy is lower than magnesium because the by-product is two waters, which have a higher mass than hydrogen
    - Water has a molecular mass of 18
    - This gives an atom economy of $\frac{120}{(120 + (2 \times 18))} \times 100 = 76.9\%$
- The reaction of magnesium carbonate with sulfuric acid produces water and carbon dioxide as by-products / waste products
    - This atom economy is lower than magnesium because the by-product is two waters, which have a higher mass than hydrogen
    - Water has a molecular mass of 18 and carbon dioxide has a molecular mass of 44
    - This gives an atom economy of = 65.9%
- You can sometimes look at the number/amount of by-products in this way to compare the atom economy of reactions without having to calculate atom economy

(2 marks)

3 (a) Rutile is a naturally occurring ore that contains titanium oxide.

Titanium can be extracted from this ore by two different methods.

Method 1 involves the electrolysis of the ore.

$$TiO_2 \rightarrow Ti + O_2$$

Method 2 involves the use of a more reactive metal to displace the titanium.

$$TiO_2 + 2Mg \rightarrow Ti + 2MgO$$

Calculate the atom economy for each reaction.

Relative atomic masses (A_r): Ti = 48, O = 16, Mg = 24

Answer

To calculate the atom economy for each reaction:

Method 1

- $\frac{48}{48 + (2 \times 16)} \times 100$; [1 mark]
- 60%; [1 mark]

Method 2

- $\frac{48}{48 + (2 \times (24 + 16))} \times 100$; [1 mark]
- 37.5%; [1 mark]

[Total: 4 marks]

- You should expect **Method 2** to have a lower atom economy because it is making two magnesium oxides with a combined molar mass of 80 as the byproduct
- This is compared to **Method 1** which makes one oxygen molecule with a molecular mass of 32 as the byproduct

(4 marks)

(b) Give **one** advantage and **one** disadvantage of using **Method 1** to extract titanium.

Answer

One advantage and **one** disadvantage of using **Method 1** to extract titanium:

Advantage

Any **one** from:

- Produces less waste; [1 mark]
- By-product/oxygen is not harmful to the environment; [1 mark]

Disadvantage

Any **one** from:

- Expensive process; [1 mark]
- It uses a substantial amount of electricity/energy; [1 mark]

[Total: 2 marks]

(2 marks)

(c) What is the atom economy of **Method 1** if the oxygen is collected and sold?

Answer

The atom economy of **Method 1** if the oxygen is collected and sold is:

- 100%; [1 mark]

[Total: 1 mark]

- If the oxygen is also collected then both / all the products are useful which means that the atom economy is 100%
- **Careful:** You may find it hard to put 100% as an answer because:
  - You are used to most / all reactions being less than 100% atom economy and also less than 100% yield
  - Your atom economy calculations tend to ask about one product as the useful product, not all products as useful products

(1 mark)

(d) Titanium is used for replacement hip joints.

Give **three** properties of titanium that make it suitable for this use.

Answer

Three properties of titanium that make it suitable for this use are:

Any **three** from:

- Non-toxic/safe to use in the body; [1 mark]
- Corrosion resistant; [1 mark]
- Strong; [1 mark]
- Durable; [1 mark]
- Low density; [1 mark]

[Total: 3 marks]

- You should not find this question too challenging as the uses of titanium is quite a common example
- The challenge of this question is writing three clearly separate and distinct properties
    - This is shown in the first marking point where non-toxic and safe to use in the body are the same point

(3 marks)

4 (a) A student investigated two different methods to produce zinc chloride.

Method 1 is the reaction of zinc oxide with dilute hydrochloric acid.

$$ZnO\ (s) + 2HCl\ (aq) \rightarrow ZnCl_2\ (aq) + H_2O\ (l)$$

Describe how a sample of zinc chloride crystals could be made from zinc oxide and dilute hydrochloric acid.

Answer

How to make a sample of zinc chloride crystals from zinc oxide and dilute hydrochloric acid:

- Add excess zinc oxide (to dilute hydrochloric acid)
  OR
  Add zinc oxide (to dilute hydrochloric acid) until no more reacts / dissolves; [1 mark]

- Filter the mixture (to remove excess zinc oxide); [1 mark]

- (Heat filtrate to) evaporate some water
  OR
  Heat to point of crystallisation
  OR
  Leave to evaporate / leave in evaporating basin; [1 mark]

- Leave to cool
  OR
  Leave until crystals form; [1 mark]
  The method must be in a correct/logical order to gain **4** marks

[Total: 4 marks]

(4 marks)

(b) A student wanted to make 15.0 g of zinc chloride using **Method 1**.

Relative atomic masses, (A_r): H = 1, Cl = 35.5, Zn = 65, O = 16

Calculate the mass of zinc oxide that the student should react with dilute hydrochloric acid to make 15.0 g of zinc chloride.

Answer

To calculate the mass of zinc oxide needed to react with dilute hydrochloric acid so that 15.0 g of zinc chloride is produced:

- M_r of $ZnCl_2$ = 65 + (2 x 35.5) = 136; [1 mark]
- Moles of $ZnCl_2$ = $\frac{15.0}{136}$ = 0.110 moles; [1 mark] *Accept 0.1102941176470 as this is during the working*
- M_r of ZnO = 65 + 16 = 81; [1 mark]
- Mass of ZnO = 0.110 x 81 = 8.93 g; [1 mark]
  A correct answer of 8.933823529411 g round to at least two significant figures without working scores 4 marks

[Total: 4 marks]

(4 marks)

(c) The percentage yield of the student's reaction to produce zinc chloride using **Method 1** was 67.4 %.

Calculate the mass of zinc chloride the student actually produced.

Answer

To calculate the mass of zinc chloride the student actually produced:

- $\frac{67.4}{100} \times 15.0$
  OR
  0.674 x 15.0; [1 mark]
- 10.1(1) g; [1 mark]
  A correct answer of 10.1(1) g without working scores 2 marks

[Total: 2 marks]

- In part (b), you were told that the student intends to make 15.0 g of zinc chloride
- Therefore, you are calculating 67.4% of the intended 15.0 g

(2 marks)

(d) **Method 2** is the reaction of zinc carbonate with dilute hydrochloric acid.

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

The atom economy for **Method 1** is 88.3%.

Calculate the atom economy for **Method 2**.

Explain the difference in the atom economies for the two methods of making zinc chloride.

Answer

To calculate the atom economy for **Method 2**:

- Total mass of products = 136 + 18 + 44 = 198
  OR
  Total mass of reactants = 125 + (2 x 36.5) = 198; [1 mark]
- Atom economy = $\frac{136}{198} \times 100$; [1 mark]
- Atom economy = 68.7%; [1 mark]

Explanation of the difference in the atom economies for the two methods of making zinc chloride:

- Method 2 has a lower atom economy
  AND
  (Because) carbon dioxide / another product is made; [1 mark]

[Total: 4 marks]

(4 marks)

5 A student made zinc chloride by reacting 15.0 g of zinc carbonate with hydrochloric acid.

$$ZnCO_3 + 2HCl \rightarrow ZnCl_2 + CO_2 + H_2O$$

The percentage yield of zinc chloride was 82.4%.

Calculate the mass of zinc chloride the student actually produced.

Relative atomic masses (A_r): C = 12 Zn = 65 O= 16 Cl = 35.5 H= 1

A. 13.4 g

B. 15.0 g

C. 16.3 g

D. 12.4 g

Answer

The correct answer is A because:

- **Step 1:** Calculate the relative formula masses of the zinc carbonate and zinc chloride :

M_r of $ZnCO_3$ = 65 + 12+ (3 x 16) = 125

M_r of $ZnCl_2$ = 65 + (2 x 35.5) = 136

- **Step 2:** Calculate the number of moles of the reactant, zinc carbonate:

$$\text{moles of } ZnCO_3 = \frac{\text{mass}}{\text{molar mass}} = \frac{15.0}{125} = 0.12 \text{ mol}$$

- **Step 3:** Use the balanced equation to deduce the theoretical yield of zinc chloride:

$ZnCO_3 + 2HCl \rightarrow ZnCl_2 + CO_2 + H_2O$

0.12 mol 0.12 mol

- **Step 4:** Calculate the actual yield of zinc chloride

$$\text{amount of } ZnCl_2 = \frac{0.12 \times 82.4}{100} = 0.0989$$

- **Step 5:** Calculate the mass of zinc chloride produced:

mass of $ZnCl_2$ = moles x molar mass

mass of $ZnCl_2$ = 0.0989 x 136 = **13.4 g**

(1 mark)