

Atom Economy

Mark Scheme



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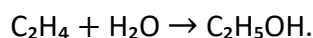
1. In the drive for a “greener chemical industry”, atom economy is a vital calculation that tells us how sustainable a reaction is by measuring how much of the starting material ends up as waste.

Circle the letter of the correct answer for each.

- a) Which statement best defines atom economy?

C – is the only correct answer.	1 mark
	Total: 1 mark

- b) The reaction for the hydration of ethene is:



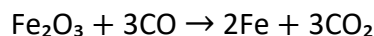
What is the atom economy of this reaction?

D – is the only correct answer.	1 mark
	Total: 1 mark

- c) A chemical company wants to choose a reaction pathway that is the most sustainable and profitable. Which of the following would be the most important factor to consider?

C – is the only correct answer.	1 mark
	Total: 1 mark

- d) Iron is extracted from iron oxide using this reaction:



Why is the atom economy for this reaction less than 100%?

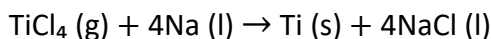
C – is the only correct answer.	1 mark
	Total: 1 mark

(Total for Question 1 is 4 marks)

2. Determine the atom economies for the following reactions.

- a) Titanium is a strong, low-density metal used in high-performance aircraft. It is extracted from titanium(IV) chloride by reacting it with sodium.

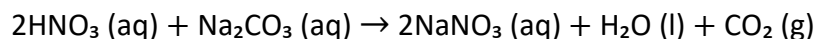
The balanced equation for the reaction is:



Calculate the atom economy for this reaction.

Calculating the sum of the relative formula masses for all of the reactants.	
$48 + (4 \times 35.5) + (4 \times 23) = 190 + 92 = 282$	1 mark
Determining the Mr of the desired product.	
$\text{Ti} = 48$	1 mark
Substitute values into the atom economy formula.	
$\text{Atom Economy} = (48 \div 282) \times 100 = 17.0\%$	1 mark
	Total: 3 marks

- b) Sodium nitrate, a compound used in fertilisers, can be made by reacting nitric acid with sodium carbonate. The balanced equation for the reaction is:



The desired product is sodium nitrate (NaNO_3).

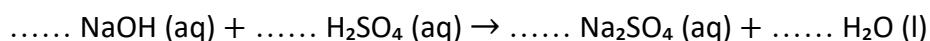
Calculate the atom economy for this reaction.

Calculating the sum of the relative formula masses for all of the reactants.	
$2 \times (1 + 14 + (3 \times 16)) + (2 \times 23) + 12 + (3 \times 16) = 126 + 106 = 232$	1 mark
Determining the Mr of the desired product.	
$2 \times (23 + 14 + (3 \times 16)) = 170$	1 mark
Substitute values into the atom economy formula.	
$\text{Atom Economy} = (170 \div 232) \times 100 = 73.3\%$	1 mark
	Total: 3 marks

(Total for Question 2 is 6 marks)

3. Sodium sulfate is an important industrial chemical used in the manufacture of detergents and soaps. It can be made by reacting sodium hydroxide with sulfuric acid.

The unbalanced chemical equation for the reaction is:



- a) Balance the equation for the reaction using the spaces provided.

1 mark for the correctly balanced reactants (the left hand side).	1 mark
1 mark for the correctly balanced products (the right hand side).	1 mark
$2\text{NaOH (aq) + H}_2\text{SO}_4 \text{ (aq)} \rightarrow \text{Na}_2\text{SO}_4 \text{ (aq) + 2H}_2\text{O (l)}$	
Accept multiples of the correct version.	
	Total: 2 marks

- b) Calculate the atom economy for this reaction.

Calculating the sum of the relative formula masses for all of the reactants.	
$2 \times (23 + 16 + 1) + (2 \times 1) + 32 + (4 \times 16) = 80 + 98 = 178$	1 mark
Determining the Mr of the desired product.	
$(2 \times 23) + 32 + (4 \times 16) = 142$	1 mark
Substitute values into the atom economy formula.	
Atom Economy = $(142 \div 178) \times 100 = 79.8\%$	1 mark
	Total: 3 marks

- c) It is important for industrial processes to use reactions with a high atom economy.

Describe **two** reasons why reactions with a high atom economy are important in industry.

A description to include any two of the following:	
Economic benefit – increases profitability / reduces costs. Less money is spent on reactants that end up as waste products.	1 mark
Environmental or sustainability benefit – It is more sustainable / better for the environment. There is less waste is produced, which reduces the need for disposal. It conserves finite raw materials.	1 mark
Reduces energy costs for separation – A higher atom economy means a purer product mixture, simplifying purification and saving energy.	1 mark
Minimises pollution – Producing less waste means there is less potential for harmful chemicals to be released into the environment	1 mark
	Total: 2 marks

This reaction has an atom economy below 100%.

- d) Explain why this is not an environmental concern for this reaction.

An explanation to include the following:	
The by-product or other product is water.	1 mark
Water is harmless / non-toxic / not a pollutant.	1 mark
	Total: 2 marks

(Total for Question 3 is 9 marks)

4. Calcium nitrate is a compound used in fertilisers.
It can be made by reacting calcium carbonate (limestone) with nitric acid.

The unbalanced chemical equation for the reaction is:



- a) Balance the equation for the reaction using the spaces provided.

1 mark for the correctly balanced reactants (the left hand side).	1 mark
1 mark for the correctly balanced products (the right hand side).	1 mark
$\text{CaCO}_3 (\text{s}) + 2\text{HNO}_3 (\text{aq}) \rightarrow \text{Ca(NO}_3)_2 (\text{aq}) + \text{H}_2\text{O (l)} + \text{CO}_2 (\text{g})$	
Accept multiples of the correct version.	
	Total: 2 marks

- b) Calculate the atom economy for this reaction.

Calculating the sum of the relative formula masses for all of the reactants.	
$40 + 12 + (3 \times 16) + 2 \times (1 + 14 + (3 \times 16)) = 100 + 126 = 226$	1 mark
Determining the Mr of the desired product.	
$40 + 2 \times (14 + 3 \times 16) = 164$	1 mark
Substitute values into the atom economy formula.	
Atom Economy = $(164 \div 226) \times 100 = 72.6\%$	1 mark
	Total: 3 marks

- c) It is important for industrial processes to use reactions with a high atom economy.

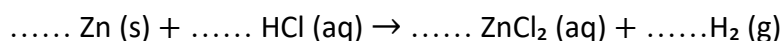
Describe **two** reasons why reactions with a high atom economy are important in industry.

A description to include any two of the following:	
Economic benefit – increases profitability / reduces costs. Less money is spent on reactants that end up as waste products.	1 mark
Environmental or sustainability benefit – It is more sustainable / better for the environment. There is less waste is produced, which reduces the need for disposal. It conserves finite raw materials.	1 mark
Reduces energy costs for separation – A higher atom economy means a purer product mixture, simplifying purification and saving energy.	1 mark
Minimises pollution – Producing less waste means there is less potential for harmful chemicals to be released into the environment	1 mark
	Total: 2 marks

(Total for Question 4 is 7 marks)

5. Zinc chloride (ZnCl_2), a salt used in soldering fluxes, can be prepared by reacting zinc metal (Zn) with hydrochloric acid (HCl).

The unbalanced chemical equation for the reaction is:



- a) Balance the equation for the reaction using the spaces provided.

1 mark for the correctly balanced reactants (the left hand side).	1 mark
1 mark for the correctly balanced products (the right hand side).	1 mark
$\text{Zn (s) + 2HCl (aq) } \rightarrow \text{ZnCl}_2 \text{ (aq) + H}_2 \text{ (g)}$ Accept multiples of the correct version.	
	Total: 2 marks

- b) Calculate the atom economy for this reaction.

Calculating the sum of the relative formula masses for all of the reactants. $2 \times (1 + 35.5) = 73 \quad 73 + 65 = 138$	1 mark
Determining the Mr of the desired product. $65 + (2 \times 35.5) = 136$	1 mark
Substitute values into the atom economy formula. $\text{Atom Economy} = (136 \div 138) \times 100 = 98.6\%$	1 mark
	Total: 3 marks

- c) Explain the difference between atom economy and percentage yield.

An explanation the following:	
Atom economy is a theoretical measure of the percentage of reactant atoms that become part of the desired product. It is calculated from the balanced equation.	1 mark
Percentage yield is a practical measure of the percentage of product actually obtained. It is calculated from the results of an actual experiment. It compares the actual yield to the theoretical yield.	1 mark
	Total: 2 marks

(Total for Question 5 is 7 marks)

6. A chemist investigates the reaction of an unknown Group 2 metal carbonate with hydrochloric acid. The formula of the metal carbonate is MCO_3 , where M is an unknown metal.

The balanced equation for the reaction is:



The chemist wants to produce the aqueous salt, MCl_2 . Once the reaction was complete the chemist calculated the atom economy. It was found to be 60.5%.

Use this information to determine the identity of the metal **M**.

Show all working.

Set up an algebraic expression for the sum of the M_r of all reactants: $\text{MCO}_3 + 2\text{HCl} = \text{M} + 12 + (3 \times 16) + 2 \times (1 + 35.5)$ Sum of reactants = $\text{M} + 133$	1 mark
Set up an algebraic expression for the M_r of the desired product (MCl_2): $M_r \text{ of } \text{MCl}_2 = \text{M} + (2 \times 35.5) = \text{M} + 71$	1 mark
Substitute the expressions and the given atom economy into the formula: $60.5 = (\text{M} + 71) \div (\text{M} + 133) \times 100$	1 mark
Rearrange the equation to remove the fraction: $0.605\text{M} + 80.465 = \text{M} + 71$	1 mark
Solve the equation for M: $\text{M} - 0.605\text{M} = 80.465 - 71$ $0.395\text{M} = 9.465$ Atomic mass of M = $9.465 \div 0.395$ Atomic mass of M = 24	1 mark
Identify the metal M: The element with a relative atomic mass of 24 is Magnesium (or Mg).	1 mark
If the student guesses magnesium without the working award 0 marks.	
	Total: 6 marks

(Total for Question 6 is 6 marks)