BENCHMARK

VCE Chemistry Assessments

Student name _____

Chemistry

Question and Answer Book

Benchmark Open SAC 4.1: Designing a synthesis pathway

- Writing time is **55 minutes**

Approved materials
- One scientific calculator

Materials supplied
- Question and Answer Book of 12 pages
- Data Book

Instructions
- Answer all questions in the spaces provided.
- Write using blue or black pen.

Students are **not** permitted to bring mobile phones or other electronic devices into the room.

Contents pages

Questions (4 questions, 40 marks) _____ 2–9

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Questions

Instructions

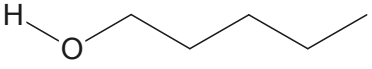
- Answer **all** questions in the spaces provided.
- Write your responses in English.
- Give simplified answers to all numerical questions, with an appropriate number of significant figures; unsimplified answers will not be given full marks.
- Show all working in your answers to numerical questions; no marks will be given for an incorrect answer unless it is accompanied by details of the working.
- Ensure that chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $H_2(g)$, NaCl(s).
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1 (8 marks)

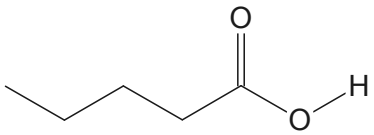
Fuels produced from plant material could replace a proportion of the transport fuels currently produced from crude oil. Esters of pentanoic acid are one family of these renewable fuels, and they can be blended with petrol or diesel. In one road trial, ten vehicles operated on petrol that contained 15% of one of these esters. Together the vehicles travelled 250 000 km, and engineers detected no damage to their engines, tanks or fuel lines.

A researcher plans to make one of these esters, pentyl pentanoate, from pentanoic acid and pentan-1-ol. She first compares the structures and physical properties of the three compounds.

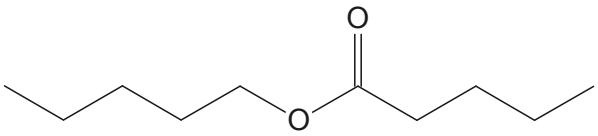
The skeletal formulae of the three compounds are shown below.



pentan-1-ol



pentanoic acid



pentyl pentanoate

The boiling points of the three compounds at normal atmospheric pressure are given in the table below.

Compound	**pentan-1-ol**	**pentanoic acid**	**pentyl pentanoate**
Boiling point (°C)	138	186	204

a. Write the molecular formula of pentyl pentanoate. 1 mark

b. Explain why the acid has a higher boiling point than the alcohol. 2 marks

c. The ester cannot form hydrogen bonds between its molecules, but it has a higher boiling point than the acid. Explain this observation. 2 marks

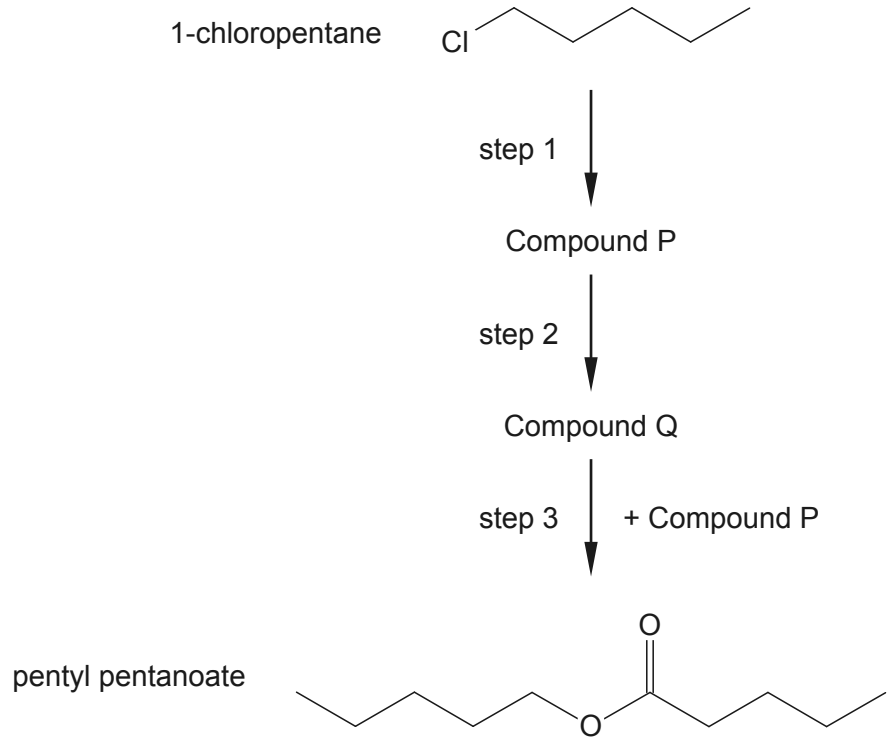
The alcohol used by the researcher has several structural isomers that are also alcohols. Only one of these isomers is a tertiary alcohol.

d. Give the IUPAC name of this tertiary alcohol. 1 mark

e. Draw the structural formula of this tertiary alcohol. Show all atoms and bonds. 2 marks

Question 2 (12 marks)

The only organic compound available in the laboratory is 1-chloropentane. The researcher therefore designs a synthesis pathway to produce the ester from this compound, as shown below. Compound P is made in step 1. Half of Compound P is then converted to Compound Q in step 2, and the other half is kept for step 3. Each step requires particular chemicals and reaction conditions.



a. Write the semistructural formulae of Compound P and Compound Q. 2 marks

b. Complete the table by giving the chemicals and conditions needed for each step. 3 marks

Step	Reagents and conditions
1	
2	
3	

c. Write the balanced equation for step 3, using semistructural formulae. Include states. 2 marks

The researcher starts with 25.0 g of 1-chloropentane. She calculates the theoretical maximum mass of the ester that this quantity could produce.

d. Calculate the maximum mass, in g, of the ester that could be made from this starting material. 2 marks

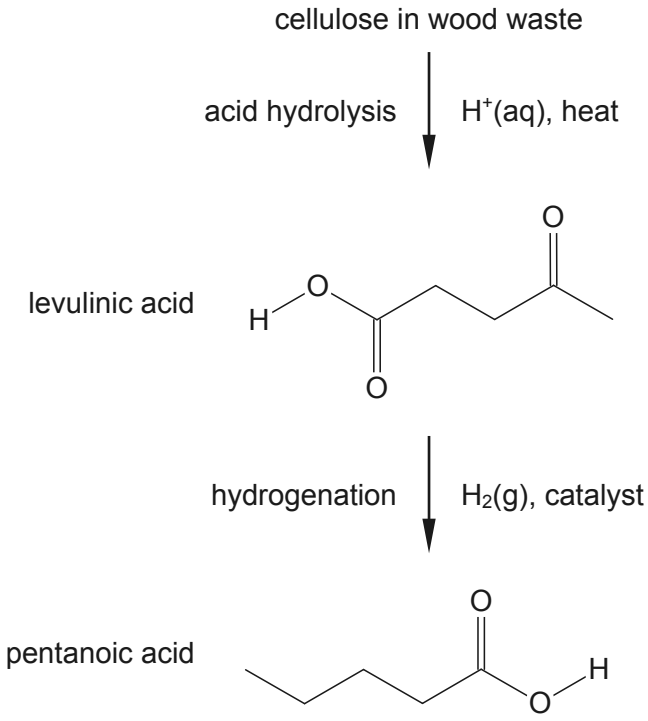
In practice, no reaction step produces the theoretical quantity of product. The researcher follows the pathway above, converting half of Compound P to Compound Q. The percentage yield of each step is shown in the table below.

Step	**1**	**2**	**3**
Percentage yield (%)	88	70	62

e. Calculate the mass, in g, of the ester that the researcher obtains. 3 marks

Question 3 (9 marks)

Pentanoic acid can also be produced from wood waste. Compared with food crops, wood waste is inexpensive, widely available and not required for food production. Researchers break down the cellulose in wood by acid hydrolysis to form levulinic acid. This acid then reacts with hydrogen gas over a catalyst, producing the acid used in Question 2. This process is Route B, shown below.



The overall equation for Route B is:

$$CH_3COCH_2CH_2COOH(l) + 2H_2(g) \rightarrow CH_3CH_2CH_2CH_2COOH(l) + H_2O(l)$$

Route A is steps 1 and 2 of Question 2, which convert the starting material, a compound manufactured from crude oil, into the same acid. Route A has a much lower atom economy than Route B.

a. Name the two functional groups present in levulinic acid. 2 marks

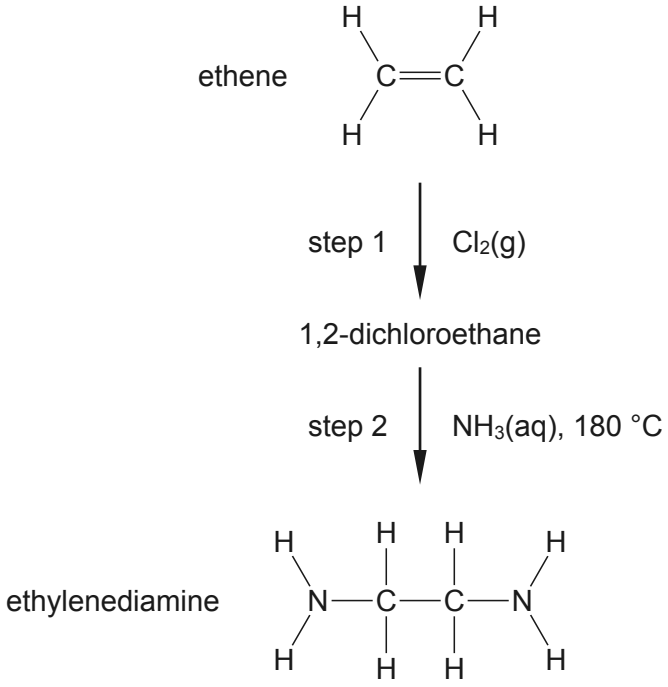
b. Calculate the atom economy of Route B. 2 marks

c. Explain how Route B applies two green chemistry principles that Route A does not. 2 marks

d. A student claims: “Route B has a higher atom economy than Route A. It will therefore always produce a greater mass of product from the same mass of starting material.” Evaluate this claim. 3 marks

Question 4 (11 marks)

Ethylenediamine is an amine that is used in the industrial production of many other chemicals, including some medicines. A company is deciding which of two routes it will use to make this amine. Its decision will consider the environmental effects of each route, the cost of the reactants and the quantity of waste produced. One industrial process starts from ethene and involves two steps, as shown below. In step 2, the product of step 1 reacts with ammonia in water at 180 °C under pressure.



a. Name the type of reaction in step 1. 1 mark

b. Give the IUPAC name of this amine. 1 mark

c. In step 2, the products are the amine and ammonium chloride. Write the balanced equation for step 2, using semistructural formulae. Include states. 2 marks

d. Calculate the atom economy of step 2. 2 marks

The same amine is also made by passing ethanolamine and ammonia over a nickel catalyst. This route also forms a mixture of other amines. The equation for this reaction is:

$$HOCH_2CH_2NH_2(g) + NH_3(g) \rightarrow H_2NCH_2CH_2NH_2(g) + H_2O(g)$$

The atom economy of this route is 76.9%.

e. In one production run, 2.00×10^3 kg of the organic reactant reacts with an excess of ammonia, producing 1.47×10^3 kg of the amine. Calculate the percentage yield of the amine. 2 marks

f. A company must choose one of the two routes to make the amine. Evaluate the two routes with reference to atom economy, catalysis and the products formed. 3 marks

End of questions

Additional writing space

Additional writing space

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