H3

MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level

CHEMISTRY **9813/01**

Paper 1 **For examination from 2026**

SPECIMEN INSERT **2 hours 30 minutes**

INFORMATION

- This insert contains information for Question 1.
- You may annotate this insert and use the blank spaces for planning. **Do not write your answers** on the insert.

This document has **4** printed pages.

Singapore Examinations and Assessment Board

CAMBRIDGE International Education

Information for Question 1

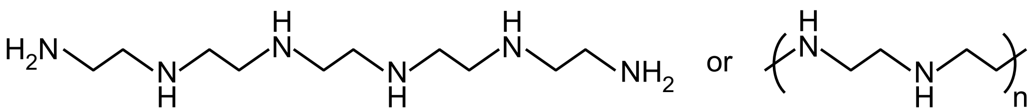
Methods of converting carbon dioxide into a suitable feedstock for fuels and the chemical industry have been a focus of chemical research. The following are abstracts from two research papers published in 2016.

Abstract 1

A highly efficient homogeneous catalyst system for the production of CH_3OH from CO_2 using pentaethylenehexamine (amine **A**) and a ruthenium-containing catalyst (catalyst **B**) at 125–165 °C in an ethereal solvent has been developed.

Ease of separation of CH_3OH is demonstrated by simple distillation from the reaction mixture. The robustness of the catalytic system was shown by recycling the catalyst over five runs without significant loss of activity. Various sources of CO_2 can be used for this reaction including air, despite its low CO_2 concentration (400 ppmv). For the first time, it was demonstrated that CO_2 captured from air can be directly converted to CH_3OH in 79% yield using a homogeneous catalytic system. (1 ppmv = 1 unit of a substance per 10^6 units of a mixture by volume)

Figure 1.1 shows the chemical cycle involved.



pentaethylenehexamine, **A**

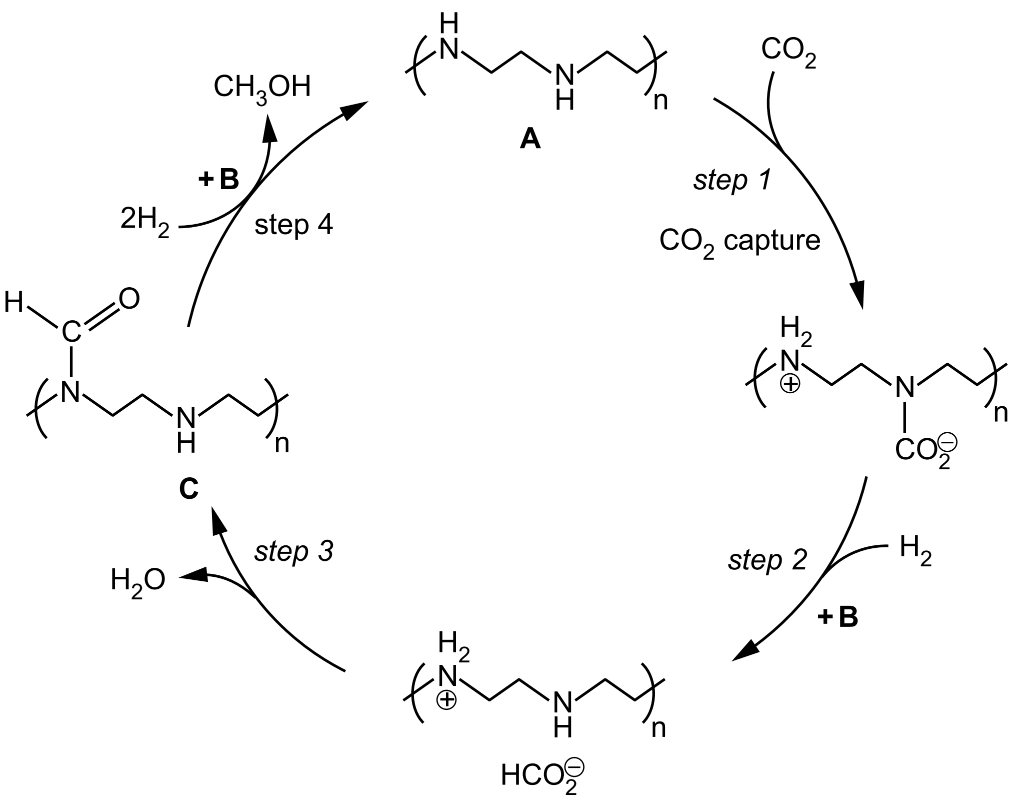


Figure 1.1

The process described in Abstract 1 requires a source of hydrogen. Two possible industrial sources are described.

- The hydrogen can be made from propane in two stages via CO. The overall change can be represented by equation 1.

$$\text{equation 1} \quad C_3H_8 + 6H_2O \rightarrow 3CO_2 + 10H_2 \qquad \Delta G^{\ominus} = -263\ \text{kJ mol}^{-1}$$

- The hydrogen can be obtained by the electrolysis of water.

$$\text{equation 2} \quad 2H_2O \rightarrow 2H_2 + O_2 \qquad \Delta G^{\ominus} = +474\ \text{kJ mol}^{-1}$$

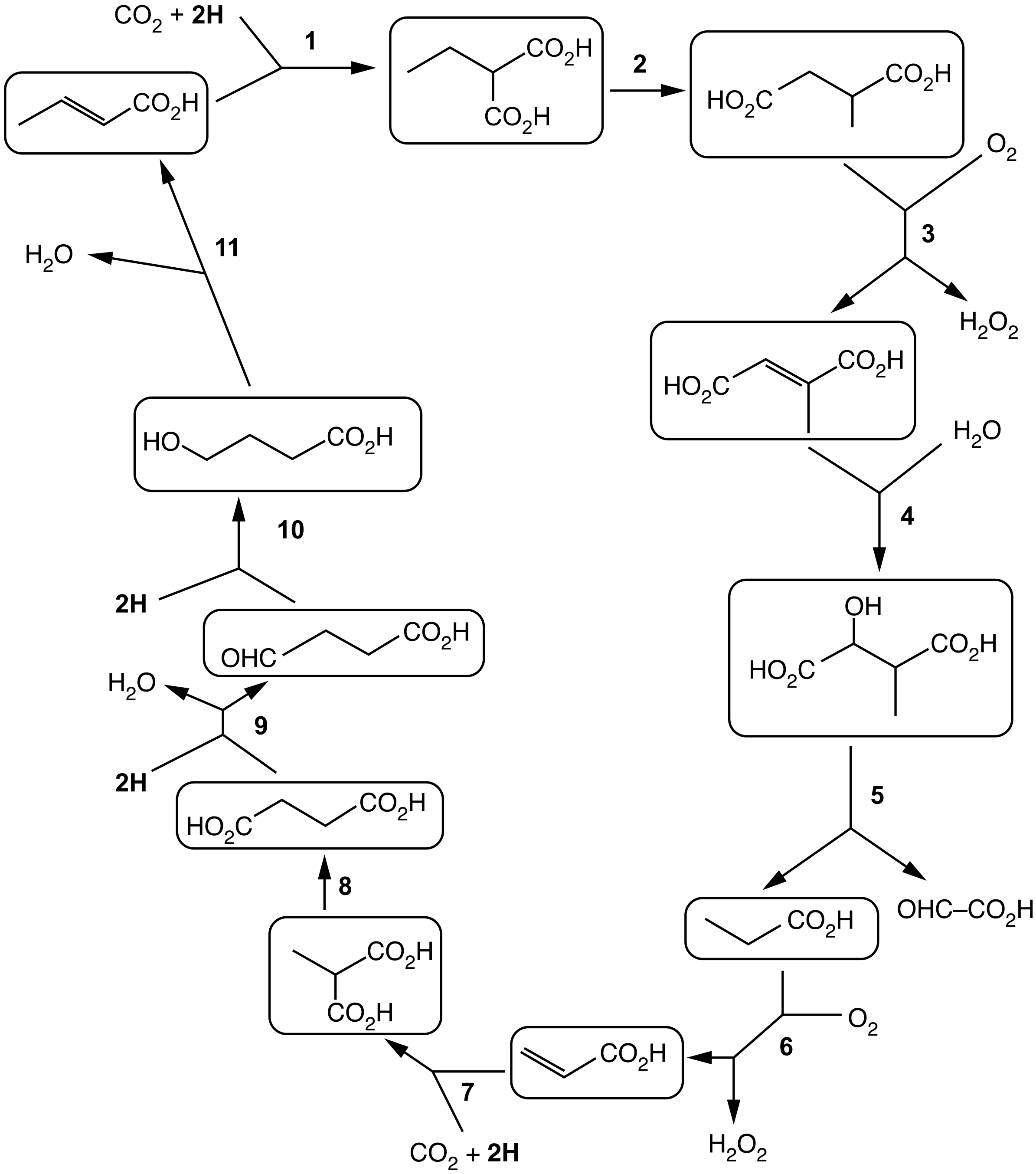
Abstract 2

Carbon dioxide (CO_2) is an important carbon feedstock for a future green economy. This requires the development of efficient strategies for its conversion into multicarbon compounds. We describe a synthetic cycle for the continuous fixation of CO_2 in vitro.

The crotonyl-coenzyme A (CoA) / ethylmalonyl-CoA / hydroxybutyryl-CoA (CETCH) cycle is a reaction network of 17 enzymes that converts CO_2 into organic molecules at a rate of 5 nanomoles of CO_2 per minute per milligram of protein. The CETCH cycle was drafted by metabolic retrosynthesis, established with enzymes originating from nine different organisms of all three domains of life, and optimized in several rounds by enzyme engineering and metabolic proofreading. The CETCH cycle adds a seventh, synthetic alternative to the six naturally evolved CO_2 fixation pathways, thereby opening the way for *in vitro* and *in vivo* applications.
(1 nanomole = 1×10^{-9} mole).

A simplified summary of the CETCH cycle can be represented by 11 steps shown in Figure 1.2.

Turn over.



(**2H** represents two hydrogen atoms transferred from a coenzyme)

Figure 1.2