1 In a closed system a reversible reaction will form an equilibrium mixture.

(a) Which of the following statements are true for a reversible reaction at **equilibrium**?

Tick (✓) the **two** correct answers.

The rate of the forward reaction is faster than the rate of the backward reaction.	☐
The position of equilibrium will not change if more product is added.	☐
The concentration of the reactants does not change.	☐
The rate of the forward reaction is the same as the rate of the backward reaction.	☐
The concentration of the reactants is the same as the concentration of the products.	☐
The position of equilibrium moves to the left when product is removed from the equilibrium.	☐

[2]

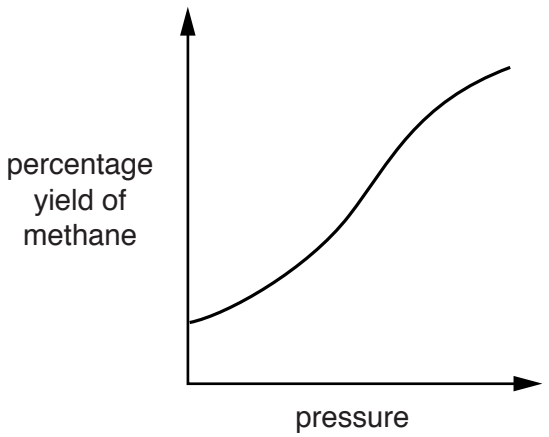
(b) Methane is a fuel that can be made by the reaction between carbon dioxide and hydrogen.

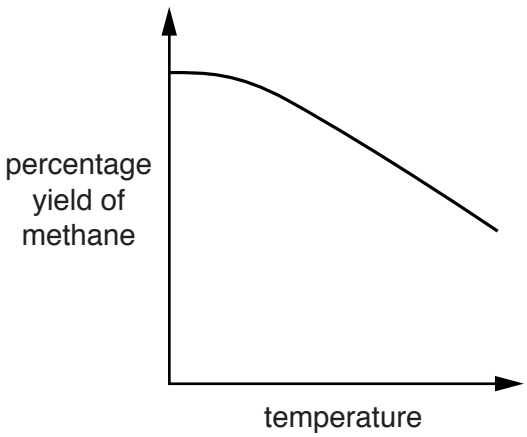
$$CO_2(g) + 4H_2(g) \rightleftharpoons CH_4(g) + 2H_2O(g)$$

Paul predicts that

- the reaction is exothermic
- there are more moles of gas on the right-hand side of the equation.

Look at the two graphs.





Do the graphs support Paul's predictions?

Explain your answer.

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2 Carbon dioxide, CO_2, reacts with hydrogen, H_2, to make methanol, CH_3OH.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O\ (g)$$

Phil investigates this reversible reaction.

He mixes carbon dioxide with hydrogen.

He lets this mixture reach equilibrium.

Phil measures the percentage yield of methanol in this equilibrium mixture.

He uses different temperatures and pressures.

Look at his results.

Pressure in atmospheres	**Temperature in °C**			
	100	200	300	400
20	90%	81%	52%	38%
40	93%	87%	70%	58%
60	96%	92%	83%	73%
80	98%	95%	90%	83%
100	99%	97%	94%	90%

(a) The percentage yield and position of equilibrium change with temperature, pressure and concentration of carbon dioxide.

Describe how the percentage yield of methanol changes with temperature and with pressure.

Describe how, and explain why, the position of equilibrium changes as extra carbon dioxide is added to the equilibrium mixture.



The quality of written communication will be assessed in your answer to this question.

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(b) Phil works as part of a team of research chemists.

It is a good idea for scientists to work as part of a team when solving scientific problems.

Explain why.

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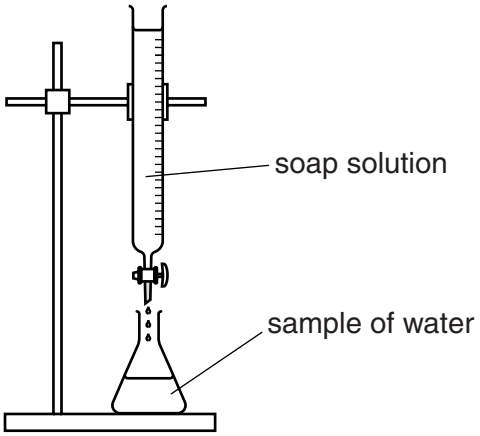
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[Total: 8]

3 Sunita and Carl are investigating 3 samples of water, **A**, **B** and **C**.

Look at the diagram. It shows the apparatus they use.



They add soap solution to samples of water and shake them.

They keep adding more soap solution until a lather remains.

Look at the table. It shows their results.

Sample		**Volume of soap solution added in cm^3**
distilled water		2.0
sample **A**	before boiling	10.0
	after boiling	10.0
sample **B**	before boiling	12.0
	after boiling	6.0
sample **C**	before boiling	7.0
	after boiling	2.0

Describe, with reasons, the types of hardness in water samples **A**, **B** and **C**.

Explain how washing soda (sodium carbonate) can soften hard water.

 The quality of written communication will be assessed in your answer to this question.

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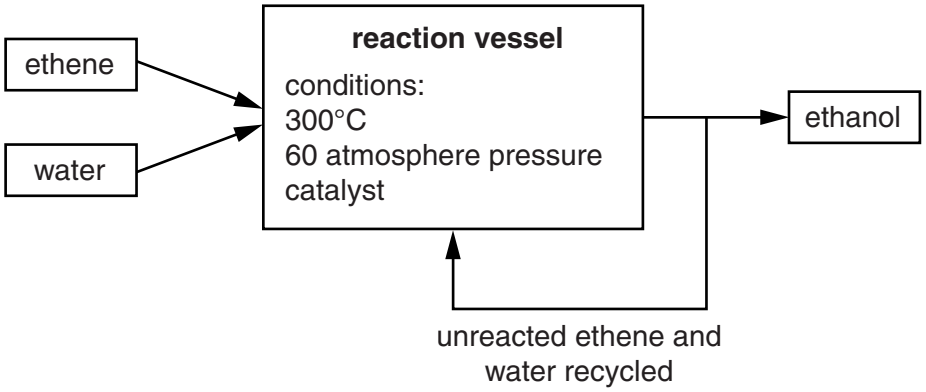
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[Total: 6]

4 Ethanol can be made from ethene and water.

The flowchart shows this process.



The symbol equation for the reaction is:

$$C_2H_4 + H_2O \rightleftharpoons C_2H_6O$$

The percentage of ethanol changes as the temperature and pressure change.

Look at the table.

It shows the percentage of ethanol at different temperatures and pressures.

Pressure in atmospheres	Percentage of ethanol (%)			
	At 100°C	At 200°C	At 300°C	At 400°C
20	15	10	5	2
40	20	15	10	5
60	40	30	20	10
80	60	50	40	20

(a) Which of the following conditions gives the **highest** percentage of ethanol?

A high pressure with high temperature

B high pressure with low temperature

C low pressure with high temperature

D low pressure with low temperature

Choose from **A**, **B**, **C** or **D**.

answer ..... **[1]**

(b) The conditions used for making **ethanol** are:

- 300°C
- 60 atmospheres pressure.

Suggest why these conditions are used even though the percentage of ethanol is only 20%.

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[Total: 3]

5 Ammonia is made from nitrogen and hydrogen in an equilibrium reaction.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The forward reaction is **exothermic**.

Look at **Table 1**.

It shows the percentage of ammonia in the equilibrium mixture at 450 °C and different **pressures**.

Pressure in atmospheres	Percentage (%) of ammonia at 450 °C
1	0.2
50	9.5
100	16.2
200	25.3

Table 1

Look at **Table 2**.

It shows the percentage of ammonia in the equilibrium mixture at 300 atmospheres and different **temperatures**.

Temperature in °C	Percentage (%) of ammonia at 300 atmospheres
400	50
450	35
500	25
550	17

Table 2

Describe and explain how changing the pressure and changing the temperature affect the position of equilibrium in the reaction between nitrogen and hydrogen.

 The quality of written communication will be assessed in your answer to this question.

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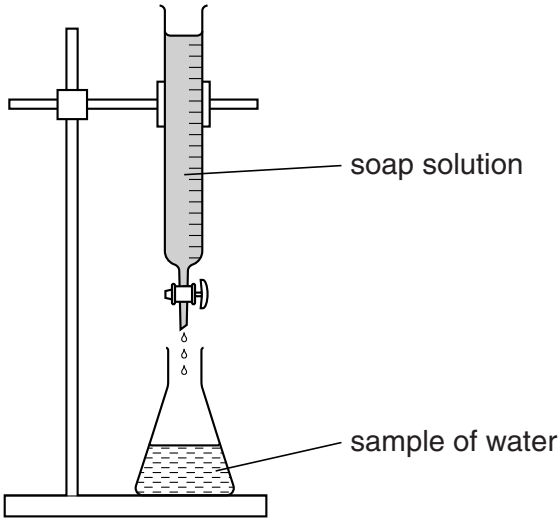
..... **[6]**

[Total: 6]

6 This question is about hard and soft water.

(a) Jean investigates the hardness of three different samples of water.

Look at the diagram of the apparatus she uses.



Jean adds drops of soap solution to the same volume of each sample of water.

After each drop she shakes the flask to see if a lather is made.

She adds more drops of soap until a lather remains on the surface.

Look at her results.

Sample of water	**Volume of soap added in cm^3**
tap water	28
boiled tap water	10
distilled water	1

What conclusion can you make about the types of hardness in tap water?

Explain your answer.

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(b) One way of softening water is to use an ion-exchange resin.

The resin contains sodium ions, Na^+.

When hard water goes through the resin the water becomes soft.

Explain how an ion-exchange resin softens water.

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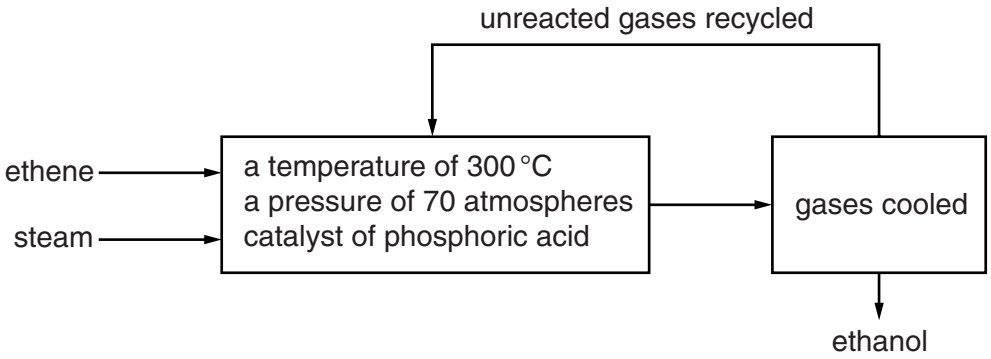
..... **[2]**

[Total: 4]

7 Ethanol (alcohol) is made by reacting ethene with steam.

$$\text{ethene} + \text{steam} \rightleftharpoons \text{ethanol}$$

Look at the flowchart.



Look at the table.

It gives some information about the percentage yield of ethanol at different temperatures and pressures.

Pressure in atmospheres	**Percentage yield**		
	200 °C	**300 °C**	**400 °C**
40	16	12	6
80	30	22	12
120	42	30	17
160	50	36	21

(a) (i) What happens to the percentage yield as the **pressure** increases?

..... **[1]**

(ii) What happens to the percentage yield as the **temperature** increases?

..... **[1]**

(b) The highest percentage yield is achieved with a temperature of 200 °C and 160 atmospheres.

The actual conditions used to make ethanol are:

- catalyst of phosphoric(V) acid
- a pressure of 70 atmospheres
- a temperature of 300 °C.

Use ideas about percentage yield and rate of reaction to suggest why each condition is used.

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(c) This process is automated.

Explain why automation is used.

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[Total: 6]