**1** Nitrogen dioxide ($NO_2$) is a brown gas.

Dinitrogen tetraoxide ($N_2O_4$) is a colourless gas.

The two gases can exist together in dynamic equilibrium according to the equation

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H = -58\,kJ/mol$$

A mixture of nitrogen dioxide gas and dinitrogen tetraoxide gas is allowed to reach equilibrium in a sealed container at 20 °C. This equilibrium mixture is brown in colour.

(a) The sealed container is immersed in hot water at 60 °C.

As the temperature of the gas mixture increases, the pressure of the gas mixture also increases.

(i) Predict the effect of the increase in temperature on the position of equilibrium.

**(1)**

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(ii) Predict the effect of the increase in pressure on the position of equilibrium.

**(1)**

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(iii) Suggest why it is difficult to predict which way the equilibrium will shift.

**(1)**

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(b) Suggest why the equilibrium mixture is a darker shade of brown at 60 °C than the equilibrium mixture at 20 °C.

**(2)**

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**(Total for Question 1 = 5 marks)**

**2** The hydrogen needed for the manufacture of ammonia is made by a process called steam reforming.

In this process, a mixture of methane and steam is passed over a nickel catalyst.

The equation for the reaction is

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +210 \text{ kJ/mol}$$

(a) In this part of the question, assume that the reaction reaches a position of equilibrium.

(i) Predict whether a high or low temperature would produce the highest yield of hydrogen.

Give a reason for your choice.

**(1)**

prediction .....

reason .....

.....

(ii) Predict whether a high or low pressure would produce the highest yield of hydrogen.

Give a reason for your choice.

**(1)**

prediction .....

reason .....

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(b) Explain how a catalyst increases the rate of a reaction.

**(2)**

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(c) Some of the carbon monoxide produced is removed in another reaction.

In this reaction, carbon monoxide is mixed with steam and passed over a heated catalyst.

The reaction is reversible and the carbon monoxide is oxidised to carbon dioxide.

(i) Write a chemical equation for this reaction.

**(2)**

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(ii) Explain why the carbon in carbon monoxide is oxidised in this reaction.

**(1)**

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(iii) The carbon dioxide produced can be removed by passing the gas through a solution of potassium carbonate, $K_2CO_3$

The potassium carbonate reacts with carbon dioxide and water to form potassium hydrogencarbonate, $KHCO_3$

Write a chemical equation for this reaction.

**(2)**

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**(Total for Question 2 = 9 marks)**