TRINITY COLLEGE

Chemistry ATAR 3+4

Chemical Equilibrium Test

DO NOT MARK THIS PAPER

TOTAL 52 Marks ***Solutions***

Please use the Multiple answer sheet for part 1 and the answer booklet for part 2.

PART 1 : Multiple Choice (15 Marks)

1. When a candle burns, there are many different chemical processes occurring. Firstly the solid candle wax ($C_{46}H_{92}O_2$) is melted by the heat of the flame. This liquid wax is then drawn up the wick, where the heat of the flame vaporises it. The wax vapour then burns in air to produce the heat and light seen. The equation below represents the physical changes taking place in the candle wax **before** combustion occurs.

$$C_{46}H_{92}O_2(s) \overset{A}{\rightleftharpoons} C_{46}H_{92}O_2(l) \overset{B}{\rightleftharpoons} C_{46}H_{92}O_2(g)$$

Classify the processes labelled A and B as endothermic or exothermic.

	A	B
(a)	endothermic	endothermic
(b)	endothermic	exothermic
(c)	exothermic	exothermic
(d)	exothermic	endothermic

Questions 2 and 3 refer to the information below.

The Haber process is the final step in the production of ammonia. It involves the reaction of nitrogen and hydrogen gases in the presence of an iron/iron oxide catalyst. This process is carried out at 350-550 °C and 15-35 MPa. The reaction can be represented by the equation below.

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

2. Which statement is **not** correct regarding the action of a catalyst?

(a) A catalyst increases the rate of reaction.
(b) A catalyst increases the average kinetic energy of the reactant particles.
(c) A catalyst allows a greater proportion of particles to react.
(d) A catalyst provides an alternate reaction pathway.

3. The iron/iron oxide catalyst is added to this system **before** it establishes equilibrium. What is the resulting effect?

(a) Both forward and reverse reactions would be favoured equally.
(b) The forward reaction rate would be increased more than the reverse reaction rate.
(c) The yield of NH_3 would be increased.
(d) The system would establish equilibrium faster.

Questions 4, 5 and 6 refer to the following information.

Consider the following equilibrium system, which is formed when solid white phosphorus reacts with fluorine gas to form phosphorus trifluoride vapour.

$$P_4(s) + 6\,F_2(g) \rightleftharpoons 4\,PF_3(g)$$

4. What is the correct equilibrium constant (K) expression for the following reaction?

(a) $K = \dfrac{[P_4][F_2]^6}{[PF_3]^4}$

(b) $K = \dfrac{4[PF_3]}{6[F_2]}$

(c) $K = \frac{[PF_3]^4}{[F_2]^6}$

(d) $K = \frac{[PF_3]^4.}{[P_4][F_2]^6}$

5. If the total volume of the system was increased, which of the following effects would **not** occur while equilibrium is being re-established?

(a) The forward reaction rate would decrease.
(b) The reverse reaction rate would be higher than the forward reaction rate.
(c) The reverse reaction rate would increase.
(d) The forward reaction rate would have the greater change in rate.

6. Once the system has re-established equilibrium (after the increase in total volume), which of the following statements would **not** be correct?

(a) The mass of $P_4(s)$ would not have changed.
(b) The concentration of $F_2(g)$ would have decreased.
(c) The number of moles of $PF_3(g)$ present would have decreased.
(d) The number of moles of $F_2(g)$ present would have increased.

7. Which one of the following statements about the following reversible reaction is **TRUE**?

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(a) $K = \frac{[SO_2]^2 [O_2]}{[SO_3]^2}$

(b) Sulfur trioxide is being formed when the reaction is at equilibrium.
(c) K is constant under all reaction conditions.
(d) A catalyst increases the yield of sulfur trioxide by increasing ΔH.

8. In which of the following reactions at equilibrium and at constant temperature is there a shift to the "left" if the pressure of the closed system is increased?

(a) $2NO_2\,(g) \rightleftharpoons N_2O_4\,(g)$

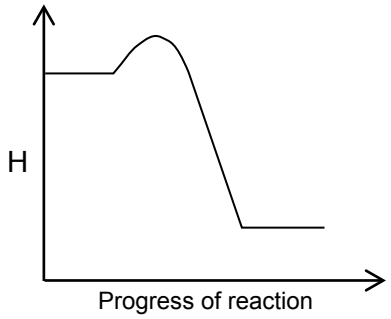
(b) $N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g)$

(c) $H_2O\,(g) + C\,(s) \rightleftharpoons H_2\,(g) + CO\,(g)$

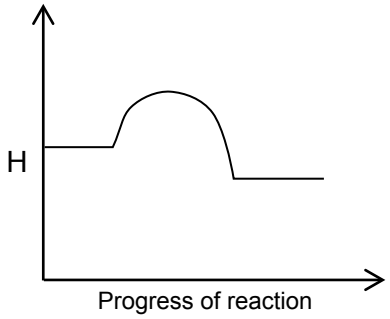
(d) $H_2\,(g) + F_2\,(g) \rightleftharpoons 2HF\,(g)$

9. Examine the following energy profile diagrams which represent four different chemical processes. You may assume the scale on the y-axis is the same for each diagram.

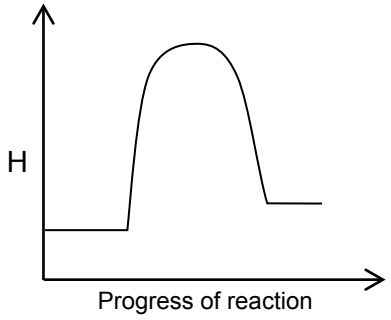
A



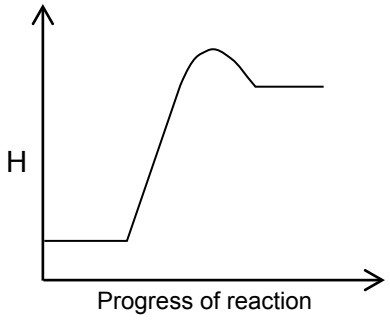
B



C



D



Considering the forward and reverse activation energies of these reactions, which is **most likely** to be a reversible reaction (i.e. the reaction that is most likely to proceed in both the forward and reverse directions)?

(a) A

(b) B

(c) C

(d) D

10. Hydrogen can be produced by the steam reforming of methane as in the following reaction:

$$CH_4\,(g) + H_2O\,(g) \rightleftharpoons CO\,(g) + 3H_2\,(g) \qquad \Delta H > 0$$

Which one of the following will increase the equilibrium yield of hydrogen?

(a) Increasing the total pressure of the reaction system.
(b) Decreasing the partial pressure of the water vapour.
(c) Removing the carbon monoxide from the system as it is produced.
(d) Decreasing the temperature of the system.

Questions 11 and 12 relate to the following information.

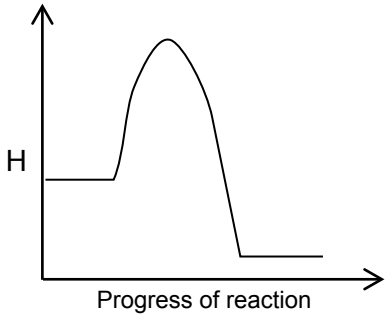
The exothermic hydrogenation of propene gas to form propane gas requires a catalyst such as platinum or nickel to be present. This reaction occurs as shown in the equation below.

$$CH_2{=}CHCH_3(g) + H_2(g) \xrightarrow{Pt} CH_3CH_2CH_3(g)$$

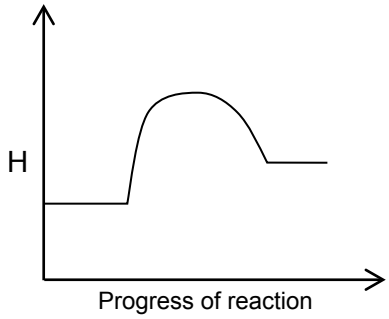
Without a catalyst present this reaction only takes place at very high temperatures. The reaction is essentially irreversible.

11. Which of the following energy profile diagrams **best** represents the **uncatalysed** reaction? (You may assume each graph has the same scale on the axes.)

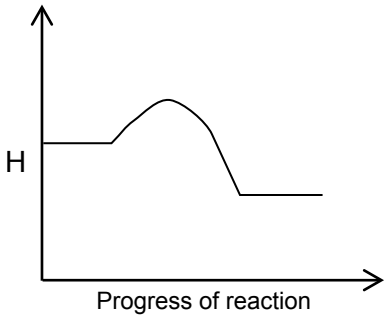
(a)



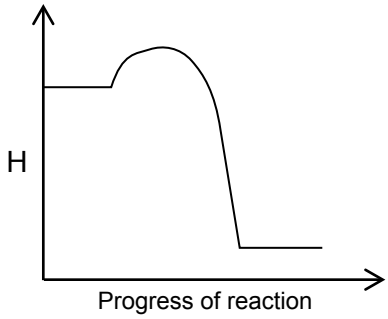
(b)



(c)



(d)



12. Which of the following is **not** an outcome of including a platinum catalyst?

(a) To increase the rate of reaction.
(b) To increase the number of successful reactant collisions.
(c) To increase the average kinetic energy of the reactant particles.
(d) To increase the proportion of particles with enough kinetic energy to react.

Questions 13, 14 and 15 relate to the following information.

The equilibrium shown below represents the endothermic decomposition of nitrogen tribromide into nitrogen and bromine vapours. Nitrogen tribromide and nitrogen are colourless gases, whereas bromine is a red vapour.

$$2\ NBr_3(g) \rightleftharpoons N_2(g) + 3\ Br_2(g)$$

If some nitrogen tribromide is injected into an empty flask;

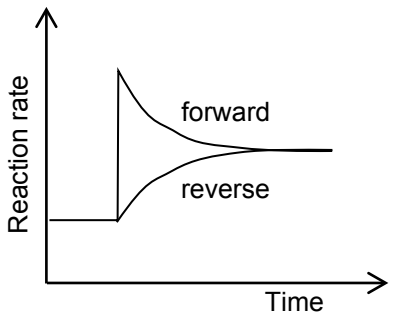
13. Which of the following is **not necessarily true** of the system once equilibrium is established?

(a) The pressure of the system would remain constant.
(b) The partial pressure of NBr_3 would remain constant.
(c) The partial pressure of Br_2 would be three times that of N_2.
(d) The partial pressure of N_2 would be half that of NBr_3.

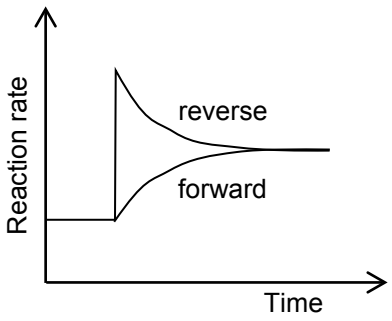
Once equilibrium was established, the temperature of the system was increased.

14. Which of the following graphs **best** shows the effect of this temperature increase on reaction rate?

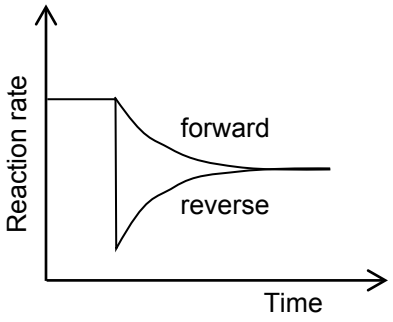
(a)



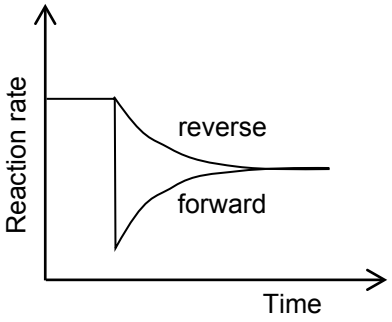
(b)



(c)



(d)



Once the system had re-established equilibrium, some $N_2(g)$ was removed.

15. Which of the following correctly states the effect of N_2 removal on the equilibrium position, as well as the corresponding observations?

	Equilibrium position	Observations
(a)	favour reverse	darker red
(b)	favour reverse	lighter red
(c)	favour forward	darker red
(d)	favour forward	lighter red

PART 2 : Short Answers (37 Marks)

Question 16 **(6 marks)**

Consider the following closed equilibrium system, which has been allowed to establish equilibrium at a temperature of 600 °C. The value of K for this reaction at 600 °C is 7.94×10^{-7}.

$$2\ Cu_2O(s) \rightleftharpoons 4\ Cu(s) + O_2(g)$$

Some additional $O_2(g)$ is injected into this equilibrium system at 600 °C. The system was then allowed to re-establish equilibrium.

(a) How has the mass of Cu(s) present changed in this new equilibrium?

(1 mark)

increased decreased no change

(b) A small amount of $Cu_2O(s)$ was then added to this equilibrium system. Explain how this would affect the equilibrium position.

(2 marks)

- **no effect**
- **solids have no measurable 'concentration' so addition or removal of a solid has no impact on equilibrium**

(c) At 800 °C, the value of K for this reaction is 3.16×10^{-5}. What does this tell you about the enthalpy change (ΔH) for this reaction? Explain your answer.

(3 marks)

- **the value of K has increased which indicates more products are present**
- **this means the forward reaction must be favoured with the addition of heat**
- **therefore the forward reaction is endothermic, ie ΔH is positive**

Question 17 **(8 marks)**

In the following equilibrium system, nitrogen, oxygen and chlorine gases combine to produce nitrosyl chloride vapour. This equilibrium system can form at temperatures of around 400 °C.

$$\underset{\textit{colourless}}{N_2(g)} + \underset{\textit{colourless}}{O_2(g)} + \underset{\textit{greenish-yellow}}{Cl_2(g)} \rightleftharpoons \underset{\textit{yellow}}{2\,NOCl(g)}$$

If an equal number of moles of $N_2(g)$, $O_2(g)$ and $Cl_2(g)$ were injected into a sealed flask at 400 °C;

(a) Explain what would happen to the forward and reverse reaction rates as the system moved to establish equilibrium.

(3 marks)

- **the forward reaction rate would initially be high, as the molecules collide to produce NOCl, and would slowly decrease as the reactants form products**
- **the reverse reaction rate would initially be zero, but as NOCl is produced it would begin to increase**
- **at equilibrium the rate of forward and reverse reactions becomes equal**

(b) Explain what would happen to the concentration of all gases as the system moved to establish equilibrium.

(3 marks)

- **the concentration of N_2, O_2, and Cl_2 would all decrease**
- **the concentration of NOCl would increase from an initial concentration of zero**
- **at equilibrium the concentration of products and reactants remain constant**

(c) Explain what you would observe as the system moved to establish equilibrium. (2 marks)

- **the greenish-yellow colour of the original mixture would become more yellow**
- **at equilibrium the colour of the system would be unchanging/constant**
- **also allow decrease in pressure, not necessarily observable though.**

Question 18 **(9 marks)**

The manufacture of ammonia on an industrial scale is carried out using the Haber process, which relies on the reversible reaction of nitrogen and hydrogen in the presence of an iron catalyst, as shown in the following equation:

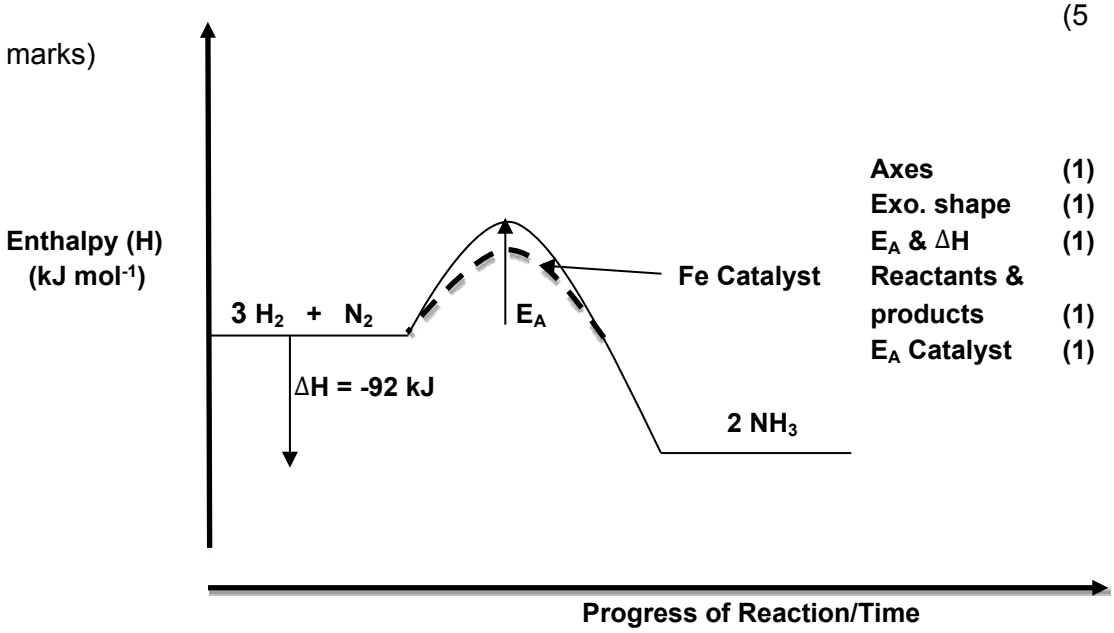
$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

The conditions for the reaction in industry must be chosen carefully, taking into consideration not only the yield, but also the rate of the reaction. Commonly, a temperature of around 500°C is used, and the reaction operated at a pressure of around 20,000 kPa. Since ammonia has a much higher boiling point than the other gases, it can easily be removed from the equilibrium mixture by condensation.

(a) On your answer sheet, draw a fully labelled enthalpy level diagram for the Haber process, showing **ΔH**, **E_A**, **catalysed** and **uncatalysed** reaction pathways, and **axes with correct units** stated.

(5 marks)

(5 marks)



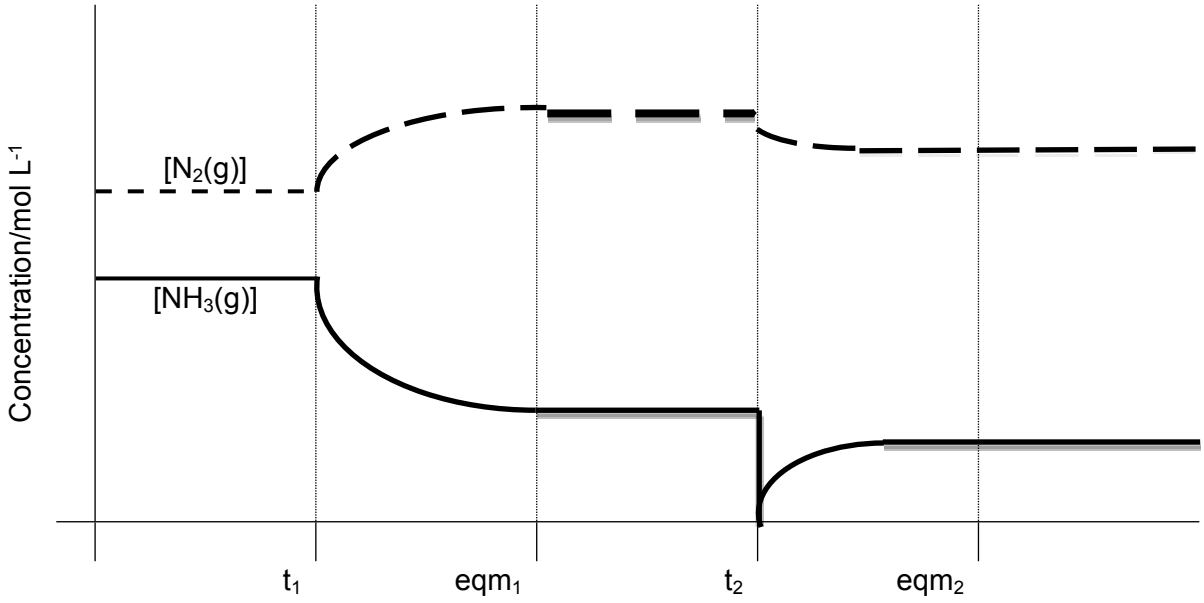
Axes	(1)
Exo. shape	(1)
E_A & ΔH	(1)
Reactants & products	(1)
E_A Catalyst	(1)

A sealed vessel containing an equilibrium mixture of nitrogen, hydrogen and ammonia was subjected to the following changes in conditions:

- At a time, t_1, the temperature of the vessel was increased
- At a time, eqm_1, the system had returned to equilibrium
- At a time, t_2, all ammonia was removed from the system
- At a time, eqm_2, the system had again returned to equilibrium

(b) Copy the following graph onto your answer sheet and show what happens to the concentrations of nitrogen and ammonia as the above changes are made.

(4 marks)



Award (2) marks for showing the correct shape and orientation for the N_2 and (2) marks for the correct shape and orientation for the NH_3 lines.

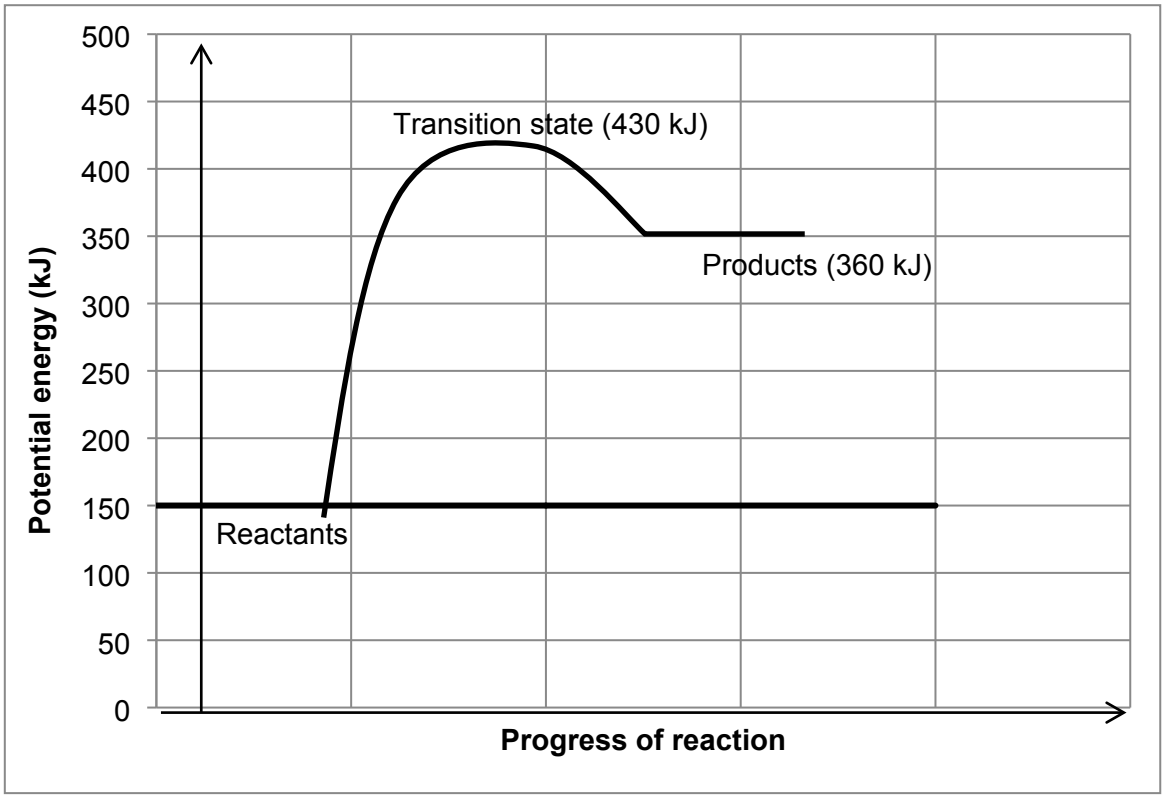
Question 19 **(7 marks)**

The first part of an energy profile diagram has been sketched on the axes below.

If the activation energy of the **reverse** reaction is 70 kJ and the heat of reaction (enthalpy change) of the **forward** reaction is 210 kJ mol^{-1};

(a) Complete the energy profile diagram above. Label the products and the transition state (activated complex).

(3 marks)



- **transition state labelled and correct graph**
- **transition state at 430 kJ**
- **products at 360 kJ NB if no not shown on graph must be correct scale.**

If a catalyst was added at the start of the reaction;

(b) Which of the following is the **most likely** new value of the activation energy for the **forward** reaction? (circle your answer)

(1 mark)

180 kJ 230 kJ 290 kJ

If the temperature of this system was decreased;

(c) Explain, in terms of the collision theory, the effect this would have on the rate of reaction.

(3 marks)

- **decreased average kinetic energy of all particles**

- **proportion of particles with Ek > Ea is decreased and less frequent collisions occur**
- **reaction rate therefore decreased**

Question 20 **(7 marks)**

The 'etching' of silicon is performed in the production of semiconductor materials, which are used in all forms of modern technology, such as mobile phones and computers. This etching can be achieved using the reversible chemical reaction below.

$$Si(s) + 4\,HF(g) \rightleftharpoons SiF_4(g) + 2\,H_2(g) + \text{heat}$$

(a) Write an equilibrium constant (K) expression for this reaction. (1 mark)

$$K = \frac{[SiF_4]\,[H_2]^2}{[HF]^4}$$

(b) Complete the following table, for each of the imposed changes stated. In each case, state the effect on the forward reaction rate and the equilibrium position.

(6 marks)

	Forward reaction rate (increase, decrease, no change)	Equilibrium position (left, right, no change)
Increase in total volume of the system	**Decrease**	**Left**
Removal of some $H_2(g)$ from system	**Decrease**	**Right**
Increase in temperature of the system	**Increase**	**Left**

End of test