Section One: Multiple-choice **25% (25 Marks)**

This section has **25** questions. Answer **all** questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 50 minutes.

2016

1. The decomposition of hydrogen peroxide in a closed system is represented by the equation below.

$$2\ H_2O_2(aq) \rightleftharpoons 2\ H_2O(\ell) + O_2(g) \qquad \Delta H < 0$$

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

(a) decreasing the concentration of hydrogen peroxide
(b) increasing the total pressure of the system
(c) decreasing the temperature of the system
(d) adding an inert gas to the system

2016

2. Sulfur can be obtained from hydrogen sulfide found in natural gas according to the equation below.

$$2\ H_2S(g) + SO_2(g) \rightarrow 2\ H_2O(g) + 3\ S(g) \qquad \Delta H > 0$$

Which one of the following changes will initially decrease the rate at which sulfur is produced?

(a) reduce the partial pressure of the hydrogen sulfide ($H_2S(g)$)
(b) increase the partial pressure of sulfur dioxide ($SO_2(g)$)
(c) add a metal catalyst to the reaction vessel
(d) heating the reaction vessel

2016

3. Consider the equilibrium system below.

$$N_2(g) + O_2(g) \rightleftharpoons 2\ NO(g)$$

If the equilibrium constant (K) for this reaction is 4.1×10^{-31}, which one of the following statements is **true** for the system where the initial partial pressures of nitrogen and oxygen were equal to each other?

(a) Once equilibrium is reached, the reverse reaction rate is much faster than the forward reaction rate.
(b) The partial pressure of NO(g) is less than the partial pressure of $N_2(g)$.
(c) The actual ratio of gaseous N_2 particles to NO gaseous particles is 1:2.
(d) When nitrogen gas is injected into a vessel containing mostly oxygen gas, the partial pressure of oxygen decreases dramatically.

See next page

2016

4. A 500 mL solution of dichromate ions and chromate ions at equilibrium is described by the equation below.

$$\underset{\text{orange}}{Cr_2O_7^{2-}(aq)} + H_2O(\ell) \rightleftharpoons \underset{\text{yellow}}{2\ CrO_4^{2-}(aq)} + 2\ H^+(aq)$$

Which of the following **best** describes the effect of adding 10 mL of concentrated potassium hydroxide solution to the system once equilibrium has been re-established.

	Relative change in concentration of $Cr_2O_7^{2-}(aq)$	Relative change in concentration of $CrO_4^{2-}(aq)$	Relative change in concentration of $H^+(aq)$	Colour change of solution
(a)	increase	decrease	decrease	more orange
(b)	decrease	increase	decrease	more yellow
(c)	no change	no change	no change	no change
(d)	decrease	increase	increase	more yellow

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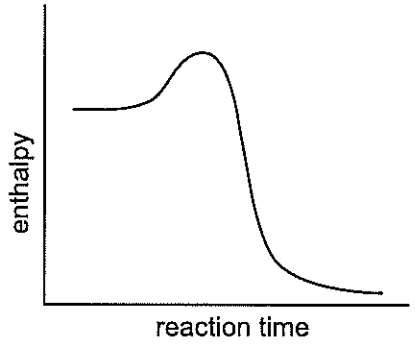
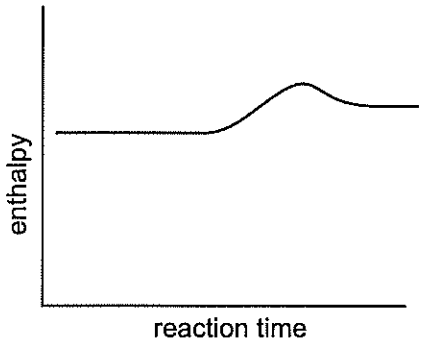
2016

8. Which of the following energy profile diagrams **best** represents a spontaneous, exothermic reaction?

(a)



(b)



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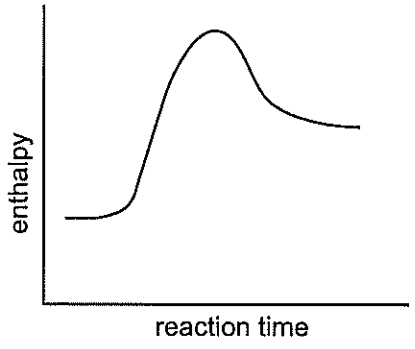
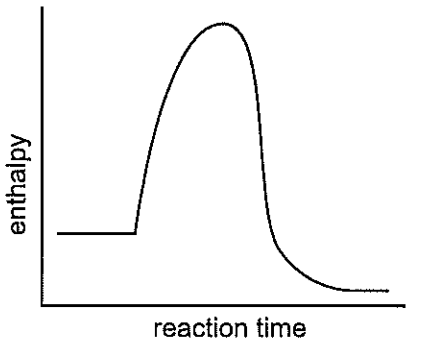


(d)



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Question 41 **(18 marks)**

Nitrogen dioxide is toxic to humans when inhaled and is a significant component of air pollution. It can be formed by the combustion of nitrogen in the air at high temperatures; firstly forming nitric oxide NO(g) and on further oxidation, forming nitrogen dioxide, $NO_2(g)$. The overall equation for this process is given here:

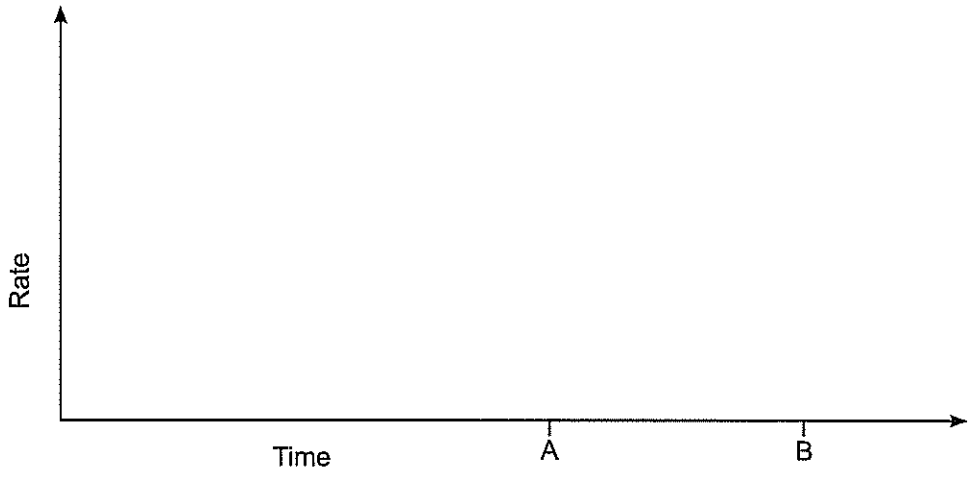
$$N_2(g) + 2\,O_2(g) \rightleftharpoons 2\,NO_2(g)$$

The following questions relate to the equilibrium system represented by this equation.

(a) Write the equilibrium expression for this reaction when it is in equilibrium. (2 marks)

(b) Assuming all other conditions remain constant, what happens to the equilibrium constant after the pressure of the system is lowered and equilibrium is re-established? (1 mark)

(c) (i) On the axes below, draw the forward (—) and reverse (- - -) reaction rates, starting at the moment the oxygen and nitrogen gases begin to react with each other until after equilibrium has been established at time A. Continue the graph until time B. (3 marks)

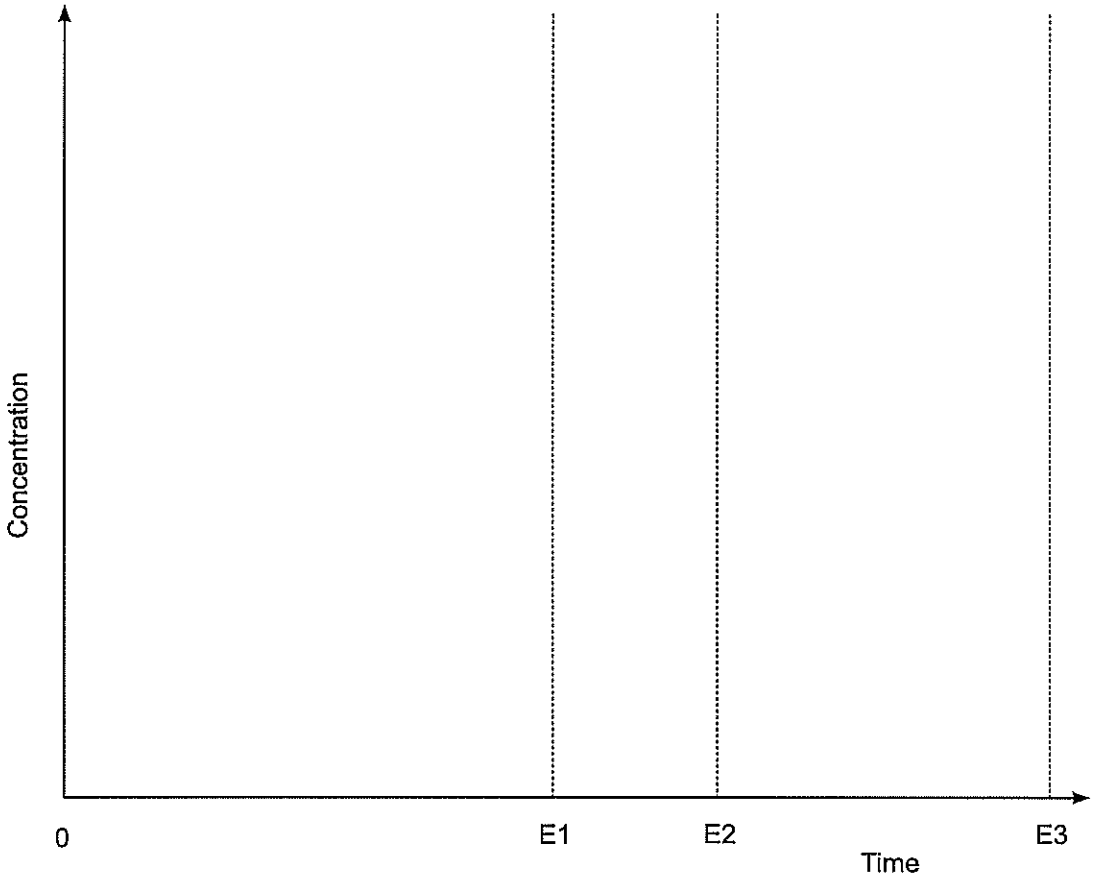


(ii) On the same axes above, draw and label clearly the effect of conducting the same reaction at a higher temperature. (2 marks)

2016 Q41 cont

(d) On the axes below, draw separate curves to show how the concentrations of the **three** gases change with time, starting at the moment the oxygen and nitrogen gases begin to react with each other until the system reaches equilibrium at Time E1. Continue the graph from Time E1 to Time E2. Assume that the initial concentrations of oxygen and nitrogen are identical.

Label clearly the line for each gas. (5 marks)



(e) At Time E2 shown on the axis, the reaction vessel is doubled in volume, and the system is then again allowed to reach equilibrium at Time E3. On the same graph above, show how the concentrations of the three gases would change in response to the change in volume, from Time E2 until equilibrium is re-established at Time E3. (3 marks)

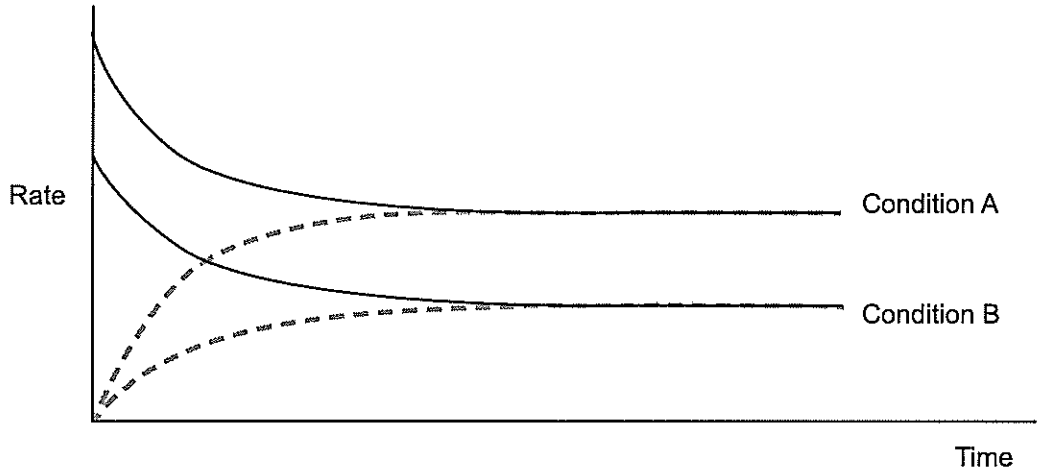
The reaction between nitrogen gas and oxygen gas occurs at high temperatures such as those found in the combustion engines of cars. The atmosphere is composed of 78% nitrogen and 21% oxygen and has been stable for millions of years.

(f) What does the stability of this composition indicate about the equilibrium constant and energy requirements of the reaction between nitrogen and oxygen gases? (2 marks)

See next page

2017

5. The following graph shows both the forward (——) and reverse (- - - -) reaction rates for a reaction under two different sets of conditions (Condition A and Condition B).



What is different about these conditions that would account for the graphs as shown?

(a) Condition A is at a higher temperature.
(b) Condition B is at a higher temperature.
(c) Condition B had a catalyst added to it.
(d) Condition B was conducted at a higher temperature and pressure.

2017

6. The reaction of acetic (ethanoic) acid with propanol is slow at room temperature. If it is assumed that the reaction proceeds by a process involving the acid accepting a proton in the first step, then the rate at which equilibrium is reached could be increased by

(a) adding a strong acid to increase the proton concentration of the reactants.
(b) lowering the temperature to reduce the collision frequency of reactants.
(c) adding a base to lower the number of protons present in the reaction vessel.
(d) adding water to the system to alter the proton concentration.

2017

7. Consider the following statements about the effect of a catalyst being added to a reaction mixture.

(i) The formation of intermediate species not found in the uncatalysed reaction.
(ii) The availability of a new reaction path having a lower activation energy.
(iii) An increase in the percentage of collisions resulting in a reaction.
(iv) The equal increase of both forward and reverse reaction rates.

Which of these statements describe what will occur when a catalyst is added to a reaction mixture?

(a) i and ii only
(b) ii and iv only
(c) i, ii and iv only
(d) i, ii, iii and iv

See next page

2017
12. A sealed glass tube at room temperature contains nitrogen dioxide (a brown gas) and dinitrogen tetroxide (a colourless gas) in equilibrium, as represented by the following equation.

$$2\,NO_2(g) \leftrightharpoons N_2O_4(g) \qquad \Delta H < 0$$

If the appearance of the gas mixture at room temperature is pale brown, which one of the following is **true** if the glass tube is placed in hot water?

(a) The gas mixture will not undergo any noticeable change in appearance.
(b) The gas mixture will become darker brown.
(c) The gas mixture will become even paler at first, but would then return to its original appearance of pale brown.
(d) The gas mixture will become colourless.

2017
13. Consider the following reaction sequence.

Step 1 $H_2O_2(aq) + I^-(aq) \rightarrow H_2O(\ell) + IO^-(aq)$
Step 2 $H_2O_2(aq) + IO^-(aq) \rightarrow H_2O(\ell) + O_2(g) + I^-(aq)$

At the same temperature, Step 1 consumes $H_2O_2(aq)$ at a rate of 4.55×10^{22} molecules per second and Step 2 consumes $H_2O_2(aq)$ at a rate of 3.67×10^{24} molecules per second.

The only source of $IO^-(aq)$ for Step 2 comes from the reaction in Step 1.

Which one of the following statements identifies, with justification, the rate-determining step?

(a) Step 1, because it is the first step in the sequence.
(b) Step 2, because it is the last step in the sequence.
(c) Step 1, because it is the slower step in the sequence.
(d) Step 2, because it is the faster step in the sequence.

2017

Questions 22 to 25 refer to the following information.

Some chemistry students were investigating the relationship between concentration and rate of reaction. In the investigation, different concentrations of hydrochloric acid were added to a sodium thiosulfate solution to produce solid sulfur. This reaction was represented by the following equation.

$$2\,H^+(aq) + S_2O_3^{2-}(aq) \rightarrow SO_2(g) + S(s) + H_2O(\ell)$$

A piece of paper with a cross drawn on it was placed under the reaction vessel. The time taken for the cross to disappear due to the formation of the precipitate was measured.

22. The independent variable was the

(a) time taken for the cross to disappear.
(b) total volume of the mixture.
(c) rate of reaction.
(d) concentration of hydrochloric acid.

23. The type of data collected and the source of data are best characterised as

(a) qualitative and primary.
(b) qualitative and secondary.
(c) quantitative and primary.
(d) quantitative and secondary.

24. When a number of laboratory groups pooled their data, one group's results were consistently higher than those of the others. This is an example of

(a) a systematic error.
(b) not enough trials.
(c) a random error.
(d) uncertainty.

25. One group chose to have its members take turns observing and timing the cross disappearing. This was poor methodology because

(a) it could make the data invalid.
(b) it introduced a possible systematic error.
(c) more trials would be needed to produce better results.
(d) the data would be less reliable.

End of Section One

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Question 28 **(10 marks)**

A hydrogen sulfate/sulfate system is represented by the following equation.

$$HSO_4^-(aq) + H_2O(\ell) \leftrightharpoons SO_4^{2-}(aq) + H_3O^+(aq)$$

(a) Predict how
- the forward reaction rate and
- the pH

will differ from their original values after the following changes are imposed on the system and equilibrium has been re-established. Use the terms **increase**, **decrease**, **no change**. (6 marks)

Change imposed by the addition of	Effect on forward reaction rate when equilibrium is re-established	Effect on pH when equilibrium is re-established
a few drops of concentrated hydrochloric acid		
a few drops of concentrated lead(II) nitrate solution		
distilled water		

(b) The reaction in part (a) is endothermic in the forward direction as written. Predict what will happen to the pH when the temperature is increased. Justify this prediction. (4 marks)

See next page

2018

2. Consider the following reaction systems at equilibrium.

System 1: $2\ NOBr(g) \rightleftharpoons 2\ NO(g) + Br_2(g)$ $K = 6.4 \times 10^{-2}$

System 2: $2\ NO(g) + 2\ H_2(g) \rightleftharpoons N_2(g) + 2\ H_2O(g)$ $K = 1.3 \times 10^{2}$

Which of these statements regarding these systems is/are true?

(i) System 2 reaches equilibrium faster than System 1.
(ii) The greatest ratio of products to reactants occurs in System 2.
(iii) Equilibrium in System 1 favours the reactants more than it does in System 2.

(a) i only
(b) ii only
(c) i and iii only
(d) ii and iii only

2018

Questions 21, 22 and 23 relate to the following information.

Ammonia, NH_3, is an industrially-important chemical. It is produced on an industrial scale by the Haber process. The reaction for the Haber process is shown below.

$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g) + 92\ kJ\ mol^{-1}$$

21. What is the immediate effect of increasing the temperature on the rates of the forward and reverse reactions in the Haber process?

(a) The rates of the forward and reverse reactions increase equally.
(b) The rates of both reactions increase while the rate of the reverse reaction increases more than the rate of the forward reaction.
(c) The rates of both reactions increase while the rate of the forward reaction increases more than the rate of the reverse reaction.
(d) The rate of the forward reaction remains unchanged while the rate of the reverse reaction increases.

22. What combination of temperature and pressure should be used to maximise the yield of ammonia, NH_3?

	Temperature for maximum NH_3 yield	**Pressure for maximum NH_3 yield**
(a)	high temperature	low pressure
(b)	high temperature	high pressure
(c)	low temperature	low pressure
(d)	low temperature	high pressure

2018

23. The Contact process, which is used to produce sulfuric acid, is another industrially-important process. The process contains several steps, one of which is the production of sulfur trioxide, SO_3, as shown below.

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g) \qquad \Delta H = -196\ kJ\ mol^{-1}$$

Which statement regarding both the Haber and Contact processes is correct?

(a) Both are exothermic and both need a suitable catalyst to occur at a satisfactory rate.
(b) Both are endothermic and both need a suitable catalyst to occur at a satisfactory rate.
(c) Both need a suitable catalyst so that the yield of their respective products is maximised.
(d) Both can achieve high rates and high yields without the need for a catalyst.

Question 37 **(12 marks)**

Gallium is present as gallium(III) oxide, Ga_2O_3, in the red mud waste from the processing of bauxite. The first step in its recovery from the red mud is the addition of hydrochloric acid, HCℓ (aq). This is represented by the equation below.

$$Ga_2O_3(s) + 6\,H^+(aq) \rightarrow 2\,Ga^{3+}(aq) + 3\,H_2O(\ell)$$

The results in the table below show the effect of temperature on the rate of gallium extraction from a red mud sample. Note that all of the other reaction conditions were constant.

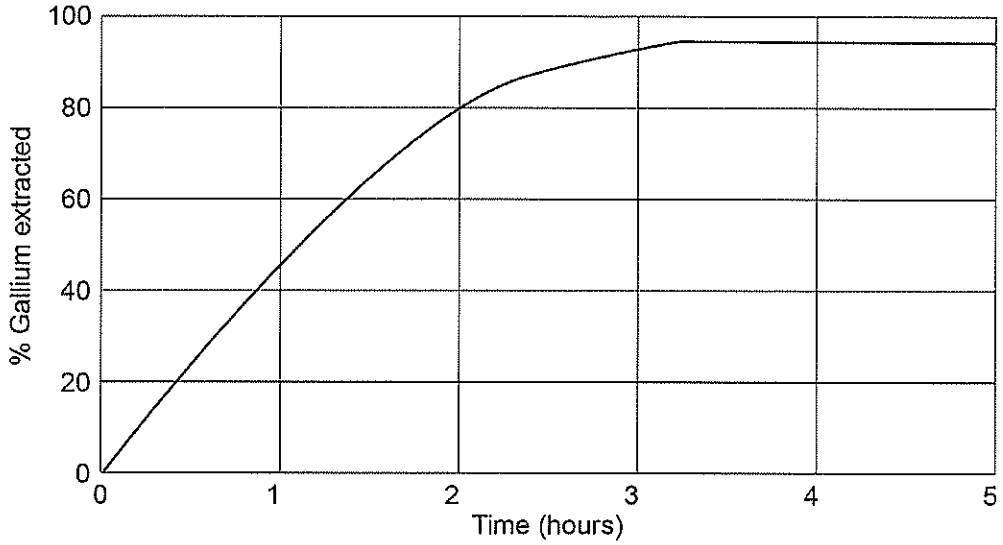
Temperature (°C)	Reaction rate (as percentage of gallium extracted after four hours)
40	77
55	88
70	95
85	96
100	97

(a) Explain the effect of temperature on reaction rate by applying collision theory. Support your explanation with an appropriate and clearly-labelled diagram. (7 marks)

See next page

Question 37 (continued)

This graph shows how the amount of gallium extracted from red mud varies over time at a hydrochloric acid concentration of 1.00 mol L^{-1}.



(b) Sketch on the graph above the result that would be obtained if the hydrochloric acid concentration was changed to 2.00 mol L^{-1}. (2 marks)

(c) Use collision theory to justify the position and shape of the graph you sketched in part (b). Assume that all other reaction conditions were kept constant. (2 marks)

In a laboratory analysis, the red mud containing gallium(III) oxide, was mixed with excess hydrochloric acid solution. The concentration of gallium(III) ions, $Ga^{3+}(aq)$, in the resulting solution was analysed and the percentage of gallium in the red mud was determined.

(d) State **one** reason why the hydrochloric acid used in this analysis needed to be in excess. (1 mark)

See next page

Question 38

(18 marks)

SpaceX is an American company that wants to send humans to Mars to explore the planet and establish a colony. One of the challenges of such a mission is finding reliable fuel sources away from Earth.

SpaceX plans to solve this problem by using the Sabatier reaction. The equation for the reaction is:

$$CO_2(g) + 4\,H_2(g) \rightleftharpoons CH_4(g) + 2\,H_2O(g) \qquad \Delta H = -165 \text{ kJ mol}^{-1}$$

The optimal conditions for this reaction are:

- temperature of 300 – 400 °C
- pressure of 200 – 300 kPa
- nickel catalyst.

The carbon dioxide would be obtained from the Martian atmosphere and the hydrogen from the hydrolysis of water extracted from either the Martian subsoil or atmosphere. The resulting methane could be used as rocket fuel while the water could be electrolysed to produce hydrogen and oxygen. The hydrogen could be fed back into the reaction vessel and the oxygen used for breathing apparatus.

(a) With reference to rates of reaction, equilibrium and economic considerations, explain why the above conditions are considered optimal for the Sabatier reaction. In your response, address any compromises in conditions. (7 marks)

See next page

Question 38 (continued)

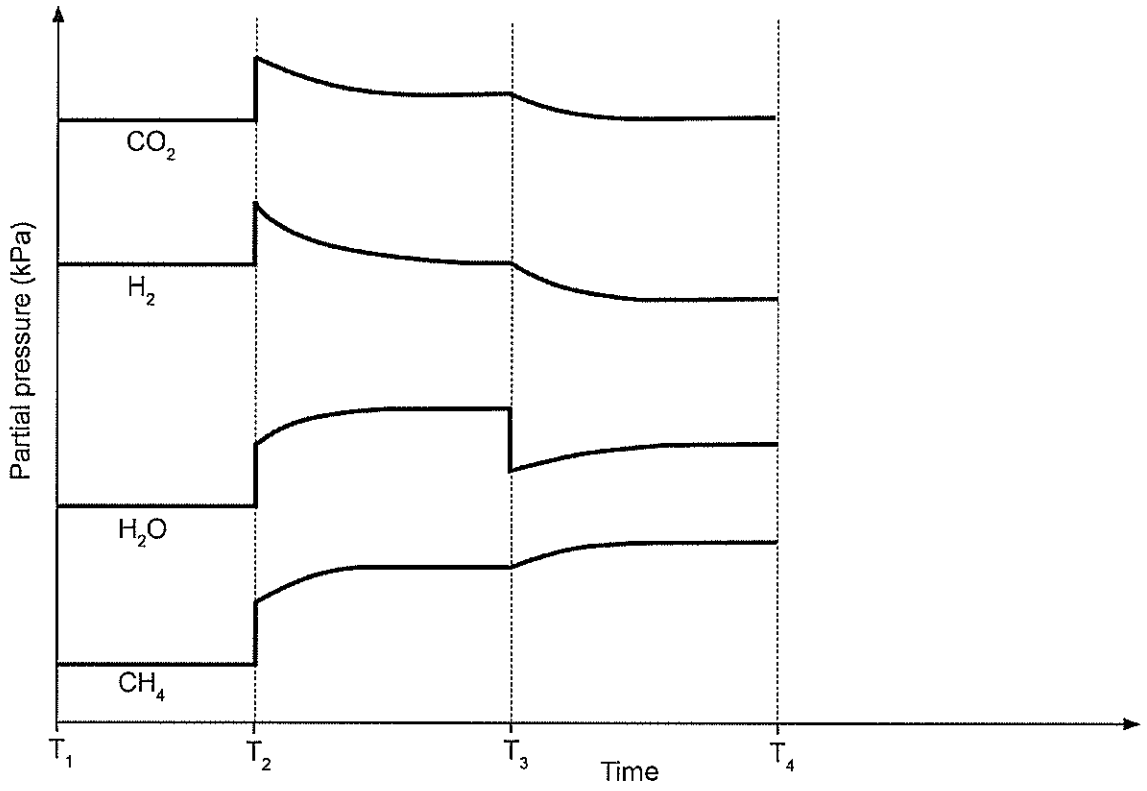
(b) Predict the effect of each of the following changes on the methane yield in the Sabatier reaction. (5 marks)

Imposed change	**Effect on methane yield** (circle your answer)		
a suitable catalyst is added	increase	decrease	no effect
the volume of the reaction vessel is increased	increase	decrease	no effect
the temperature is increased	increase	decrease	no effect
methane is removed through a special valve as soon as it forms	increase	decrease	no effect
the partial pressure of carbon dioxide is decreased	increase	decrease	no effect

See next page

Graphs can be drawn to show the effects of imposed changes on equilibrium systems. The graph below shows the effects of some changes that might be made to the reacting system in a flexible vessel.

$$CO_2(g) + 4\,H_2(g) \rightleftharpoons CH_4(g) + 2\,H_2O(g) \qquad \Delta H = -165 \text{ kJ mol}^{-1}$$



With reference to the above graph, answer the following questions.

(c) (i) What happened at T_1? (1 mark)

(ii) Identify the change imposed at each time in the table below. (2 marks)

Time	Change imposed on the system
T_2	
T_3	

(iii) The temperature of the reaction vessel was decreased at T_4. Sketch on the graph above to show how this affected the partial pressures of all species present. Include any changes to scale and continue until a new equilibrium is established. (3 marks)

See next page

2019

2. The Haber Process involves the following equilibrium reaction:

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

A number of closed reaction vessels were set up containing the gases shown in the table below.

Reaction vessel	Gases initially present
i	nitrogen, hydrogen
ii	nitrogen
iii	ammonia
iv	hydrogen, ammonia

In which of the above closed reaction vessels would equilibrium be established after a period of time?

(a) i only
(b) i and iii only
(c) i, iii and iv only
(d) ii, iii and iv only

See next page

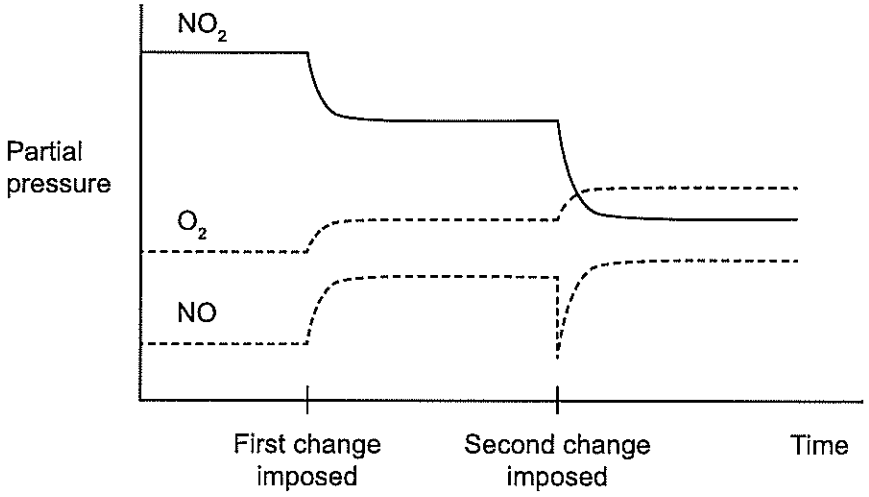
2019

Questions 3 and 4 refer to the following information.

Nitrogen dioxide, $NO_2(g)$, is formed when nitrogen monoxide, NO(g), undergoes oxidation as shown below.

$$2\,NO(g) + O_2(g) \rightleftharpoons 2\,NO_2(g) \qquad \Delta H = -62\ kJ\ mol^{-1}$$

A change was imposed on an equilibrium gas mixture of NO_2, NO and O_2. The mixture returned to equilibrium and another change was imposed. The following graph shows the effects of the two changes.



3. Identify the imposed changes that **best** account for the shape of the graph.

	First change	Second change
(a)	the temperature is decreased	the partial pressure of O_2 is increased
(b)	the temperature is decreased	the partial pressure of NO is decreased
(c)	the temperature is increased	the partial pressure of O_2 is increased
(d)	the temperature is increased	the partial pressure of NO is decreased

4. What do the initial partial pressures of the three gases indicate?

(a) The relative proportions of the gases present at equilibrium.
(b) That there is initially no NO gas present in the system.
(c) That the NO_2 gas reaches equilibrium first.
(d) That the O_2 and NO gases are producing NO_2 at a faster rate than they are being formed.

See next page

Question 34 **(12 marks)**

Consider the reaction between magnesium carbonate, $MgCO_3(s)$, and dilute nitric acid, $HNO_3(aq)$.

$$MgCO_3(s) + 2\,H^+(aq) \rightarrow Mg^{2+}(aq) + CO_2(g) + H_2O(\ell)$$

The following data was obtained from the addition of excess 0.500 mol L^{-1} nitric acid to 5.00 g of magnesium carbonate.

Time (min)	0	1.0	2.0	3.0	4.0	5.0	6.0
Volume of gas produced (mL)	0	12	18	25	32	33	33

(a) Draw a labelled graph of the data provided in the grid below. (4 marks)

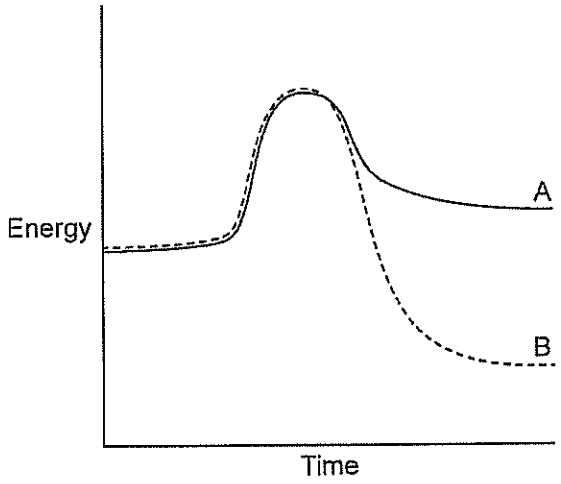
A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate clearly that you have redrawn it on the spare page.

See next page

(b) Explain the shape of your graph in part (a) by referring to Collision Theory. (6 marks)

(c) Sketch and label a line on your graph in part (a) that shows the effect of conducting the same experiment at a higher temperature. (2 marks)

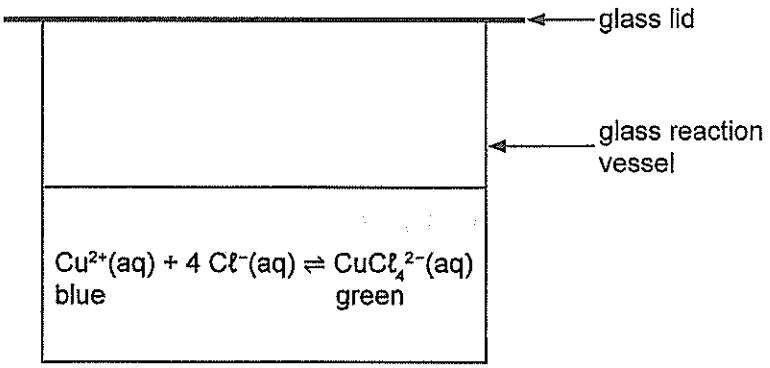
2020
8. Energy profile diagrams for two different chemical reactions (A and B) are shown below.



Which of these reactions is the more likely to be reversible and why?

(a) Reaction A, because its forward reaction is endothermic.
(b) Reaction B, because its forward reaction is exothermic.
(c) Reaction A, because the activation energy of its reverse reaction is smaller than that for Reaction B.
(d) Neither, because the activation energies of their forward reactions are the same.

2020
12. A group of Chemistry students observed a demonstration in which solid sodium chloride was added to an aqueous solution of copper(II) chloride in a glass reaction vessel. A tightly-fitting lid was placed on the reaction vessel. The solid sodium chloride was allowed to dissolve and then the entire system was heated and then cooled. This resulted in colour changes. The reaction system is shown below.



The students were asked to decide if the system was open or closed and if the demonstration involved chemical and/or physical processes. Their responses are shown in the following table.

Which student has the correct responses?

	Student	Type of system (open/closed)	Type of process (chemical/physical)
(a)	1	closed	physical
(b)	2	closed	chemical
(c)	3	closed	chemical and physical
(d)	4	open	chemical

2020
16. Which of the following is **not** a characteristic of a system in dynamic equilibrium?

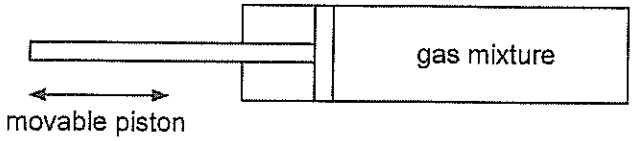
(a) The mass of the reactants equals the mass of the products.
(b) Reactants are forming products and products are forming reactants.
(c) The rates of the forward and reverse reactions are equal.
(d) The position of the equilibrium is affected by temperature.

OFF

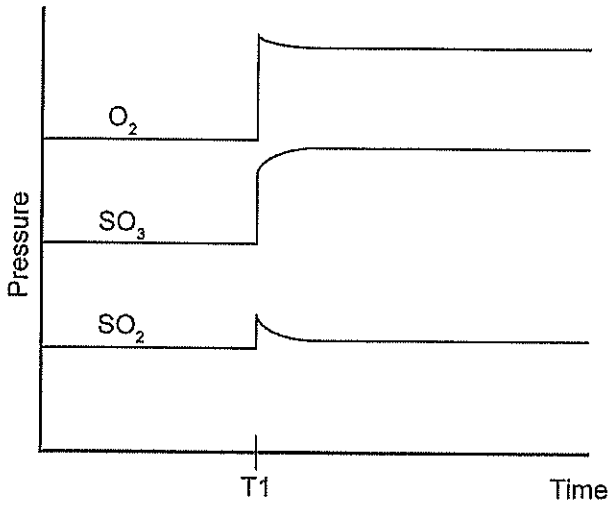
2020
24. Consider the following equilibrium:

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g) + \text{heat}$$

A mixture of these gases was at equilibrium in a sealed container with a movable piston, as shown below.



A change was applied to the system at T1 and the results of this change are shown in the following graph.



What was the change that occurred at T1?

(a) An inert gas was added to the reaction vessel.
(b) The reaction vessel was heated.
(c) A catalyst was added to the reaction vessel.
(d) The volume of the reaction vessel was decreased.

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2020

Question 29 **(11 marks)**

Some hydrogen sulfide and methane were sealed inside a reaction vessel and the following equilibrium was established:

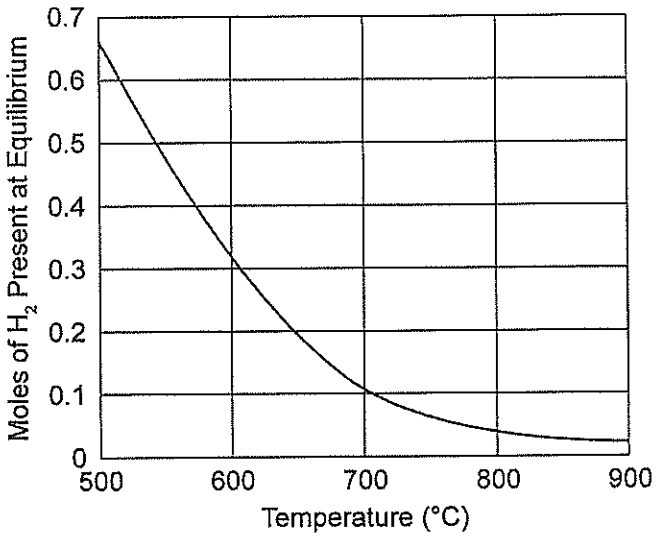
$$2\ H_2S(g) + CH_4(g) \rightleftharpoons CS_2(\ell) + 4\ H_2(g)$$

(a) Write the equilibrium constant expression (K) for this reaction system. (2 marks)

(b) Some methane was removed from the reaction vessel. What effect did this have on the position of the equilibrium? Use collision theory to justify your answer. (5 marks)

See next page

The temperature inside the reaction vessel was increased. The heating process was stopped every so often and, once equilibrium had been established at the attained temperature, the amount of hydrogen present in the system was measured. The results are shown on the following graph.



(c) Using the graph and your answer to part (a), predict the effect of an increase in temperature on the numerical value of K. Justify your prediction. (4 marks)

Question 34 **(10 marks)**

The Haber process is used to make ammonia. The balanced equation for the process is:

$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g) + 92\ kJ$$

The Haber process provides challenges for industrial operators in relation to the rate of ammonia production and the ammonia yield. This is reflected in the following quotation taken from *Chemistry and Engineering News*:

'The reaction has good yields at very low temperatures ... but the rate is sluggish. To speed it up, chemists raise the temperature. But at those high temperatures, the reaction's thermodynamics change, and the yield goes down.'

(a) State whether you agree with the claims about the effects of temperature on the yield of ammonia. Justify your statement using Le Châtelier's Principle. (4 marks)

(b) State whether you agree with the claims about the effects of temperature on the rate of the Haber process. Justify your statement using collision theory. (6 marks)

End of Section Two

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2021
20. Consider the following reversible reaction:

$$2\ NO(g) + C\ell_2(g) \rightleftharpoons 2\ NOC\ell(g) \qquad K_c = 6.5 \times 10^4 \text{ at } 35\ °C$$

Which of the following statements describes the relative concentrations of reactants and products in this system when equilibrium is established in a closed vessel at 35 °C?

(a) The concentrations of reactants and products will be equal.
(b) There will be a greater concentration of products than reactants.
(c) The reactant concentration will be greater than that of the products.
(d) The concentrations of $NOC\ell$ and NO will be double the concentration of $C\ell_2$.

2021
23. The equilibrium position of a system depends on the concentrations of

(a) reactants only.
(b) products only.
(c) reactants and products.
(d) neither reactants nor products.

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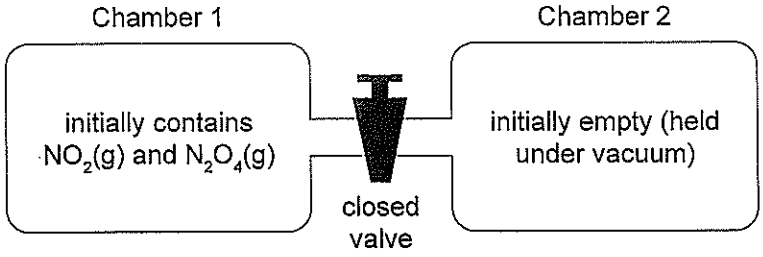
2021

Questions 24 and 25 refer to the following information.

Equal moles of nitrogen dioxide gas (NO_2) and dinitrogen tetroxide gas (N_2O_4) are sealed inside one half of a two-chamber reactor as shown below. The temperature inside both chambers is 25 °C.



After a while, the following equilibrium is established inside Chamber 1:

$$2\ NO_2(g) \rightleftharpoons N_2O_4(g) + 58\ kJ\ mol^{-1}$$

reddish brown *colourless*

2021

24. More $N_2O_4(g)$ is added to Chamber 1. What observations would be made about the colour of the gas mixture and its temperature after a new equilibrium is established?

	Gas mixture colour	Temperature
(a)	darker brown	higher
(b)	darker brown	lower
(c)	paler brown	higher
(d)	paler brown	lower

2021

25. The valve between the chambers is opened, allowing the gas mixture in Chamber 1 to fill both chambers. Which statement describes the initial and final observations of the gas mixture's colour as a new equilibrium is established?

	Initial observation when tap is opened	Observation as equilibrium is re-established
(a)	paler brown	became darker
(b)	paler brown	became paler
(c)	darker brown	became darker
(d)	darker brown	became paler

End of Section One

2021

Question 32 **(14 marks)**

Ammonia is manufactured industrially by the Haber process, the reaction equation being:

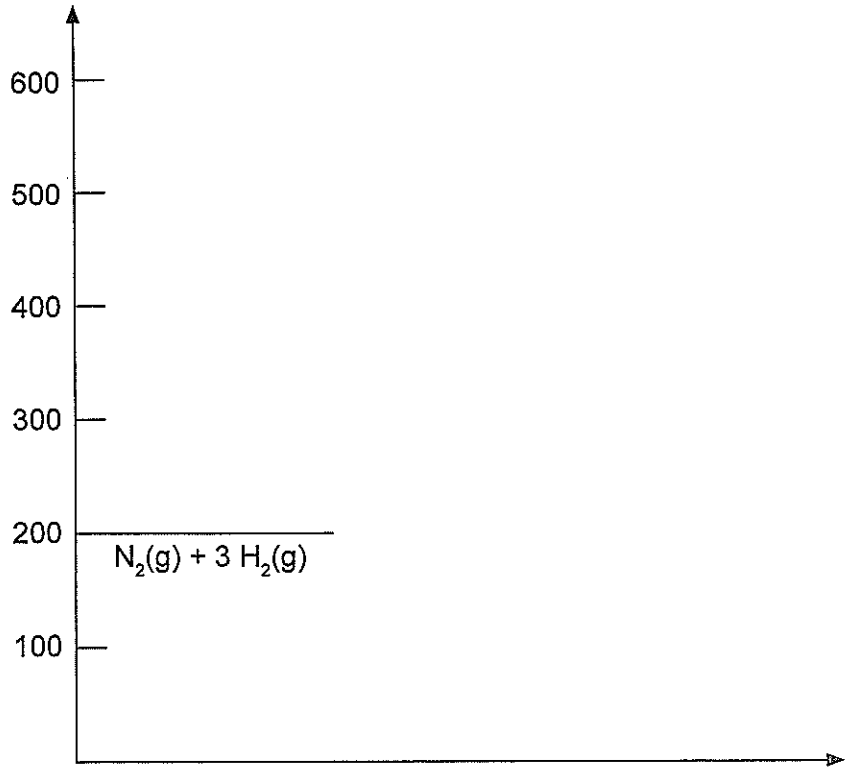
$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g) + 92\ kJ$$

At 400 °C the equilibrium constant of this reaction is equal to 1.60×10^{-4} and the activation energy of the forward reaction is approximately 4.00×10^2 kJ mol^{-1}.

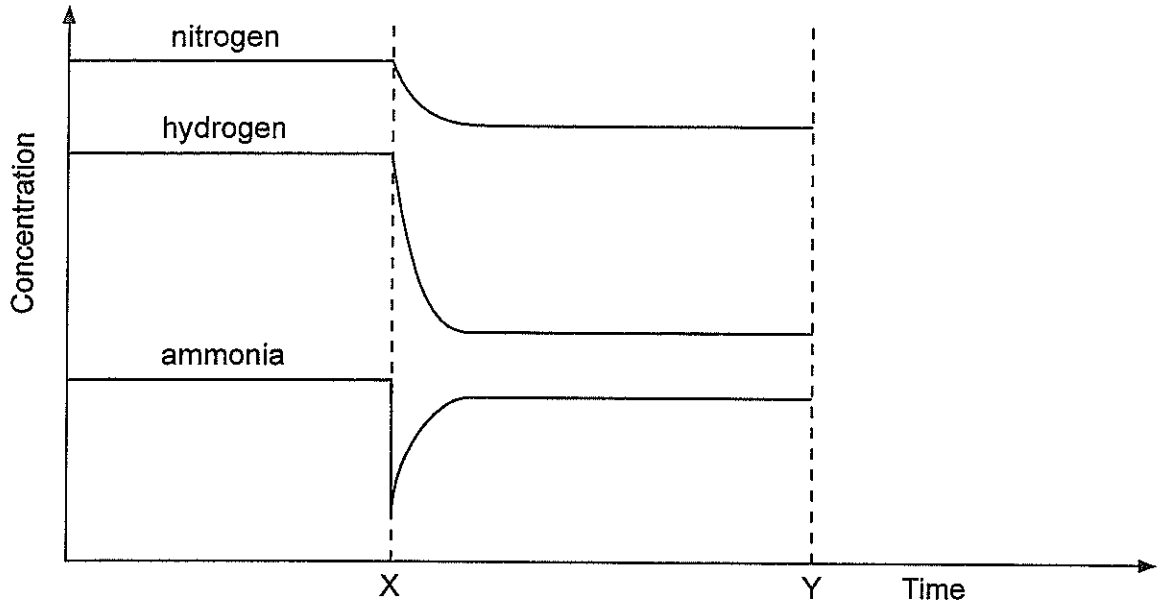
(a) Write the equilibrium constant expression for this reaction. (2 marks)

(b) Use the following axes to sketch an energy profile diagram for the Haber process.
Label the:

- axes
- products
- activation energy
- change in enthalpy. (4 marks)



Some hydrogen, nitrogen and ammonia were sealed in a reaction vessel and their concentrations were monitored for a period of time, as shown in the following graph:



(c) A change was made to the reaction system at time X. Identify this change and use collision theory to explain the shapes of the curves in the region X–Y. (5 marks)

(d) The temperature of the reaction system was increased at time Y. Show on the graph how this affected the concentrations of hydrogen, nitrogen and ammonia as the system returned to equilibrium. (3 marks)

Question 38 **(12 marks)**

Sulfuric acid is manufactured by the Contact process, the steps of which are outlined below.

Step One: Molten sulfur is burned in air at approximately 1000 °C:

$$S(\ell) + O_2(g) \rightarrow SO_2(g) + 297 \text{ kJ}$$

Step Two: The resulting sulfur dioxide is converted to sulfur trioxide as shown in the following equilibrium reaction. It is conducted at a temperature of about 450 °C with a V_2O_5 catalyst at a pressure of between 100 and 200 kPa:

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g) + 198 \text{ kJ}$$

Step Three: The resulting sulfur trioxide is absorbed into sulfuric acid, producing oleum ($H_2S_2O_7$). Water is added to the oleum, producing 18 mol L^{-1} sulfuric acid:

$$SO_3(g) + H_2SO_4(\ell) \rightarrow H_2S_2O_7(\ell)$$

$$H_2S_2O_7(\ell) + H_2O(\ell) \rightarrow 2\ H_2SO_4(aq)$$

Use your understanding of collision theory and chemical equilibrium to discuss the reaction conditions for Steps 1 and 2 of the Contact process, given that the aim is to produce the greatest yield in the shortest time. In your discussion, also address economic concerns where appropriate.

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