

# F322: Chains, Energy and Resources

## 2.3.2 Rates and Equilibria

1. Dilute aqueous hydrogen peroxide,  $\text{H}_2\text{O}_2(\text{aq})$ , is used to sterilise contact lenses.

Dilute  $\text{H}_2\text{O}_2(\text{aq})$  slowly decomposes at room temperature to produce oxygen and water.

The decomposition of  $\text{H}_2\text{O}_2(\text{aq})$  can be made faster by:

- increasing the concentration of the  $\text{H}_2\text{O}_2(\text{aq})$ ,
- adding a small amount of manganese(IV) oxide catalyst,
- heating the solution to  $60\text{ }^\circ\text{C}$ .

(i) Construct the equation for the decomposition of  $\text{H}_2\text{O}_2$ .

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[1]

(ii) Explain why increasing the concentration of  $\text{H}_2\text{O}_2(\text{aq})$  increases the rate of decomposition.

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[2]

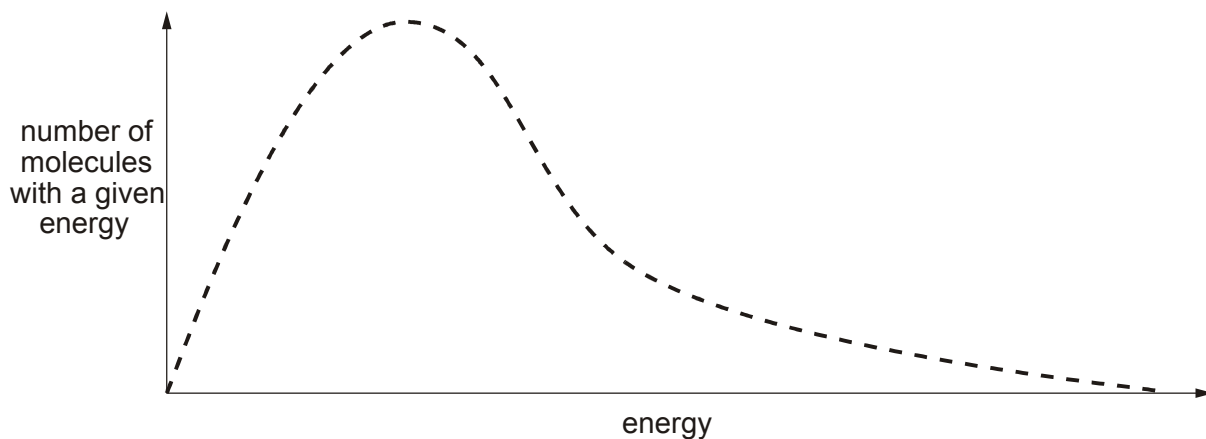
(iii) Explain how the catalyst can increase the rate of decomposition of  $\text{H}_2\text{O}_2(\text{aq})$ .

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[2]

- (iv) Explain why increasing the temperature of  $\text{H}_2\text{O}_2(\text{aq})$  increases the rate of decomposition.

As part of your answer, you should add a second curve and any necessary labels to the Boltzmann distribution of molecular kinetic energies shown below.



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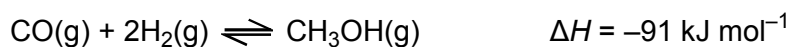
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[3]

[Total 8 marks]

2. In the chemical industry methanol,  $\text{CH}_3\text{OH}$ , is synthesised by reacting together carbon monoxide and hydrogen in the presence of copper, zinc oxide and alumina which act as a catalyst. This is a reversible reaction.



- (a) High pressures and low temperatures would give the maximum equilibrium yield of methanol.

Explain why.

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[2]

- (b) Explain why the actual conditions used in the chemical industry might be different from those in (a) above.

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[2]

[Total 4 marks]

3. Chemical companies are using catalysts to develop processes that are more sustainable. These processes reduce costs and are less harmful to the environment.

Suggest **two** ways in which the use of catalysts helps chemical companies to make their processes more sustainable.

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[Total 4 marks]

4. Nitrogen dioxide,  $\text{NO}_2$ , and dinitrogen tetroxide,  $\text{N}_2\text{O}_4$ , take part in the following equilibrium.



- (a) State le Chatelier's principle.

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[2]

(b) Describe, and explain, what would happen to the position of the  $\text{NO}_2/\text{N}_2\text{O}_4$  equilibrium if the following changes are made.

(i) The temperature is increased.

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[2]

(ii) The pressure is increased.

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[2]

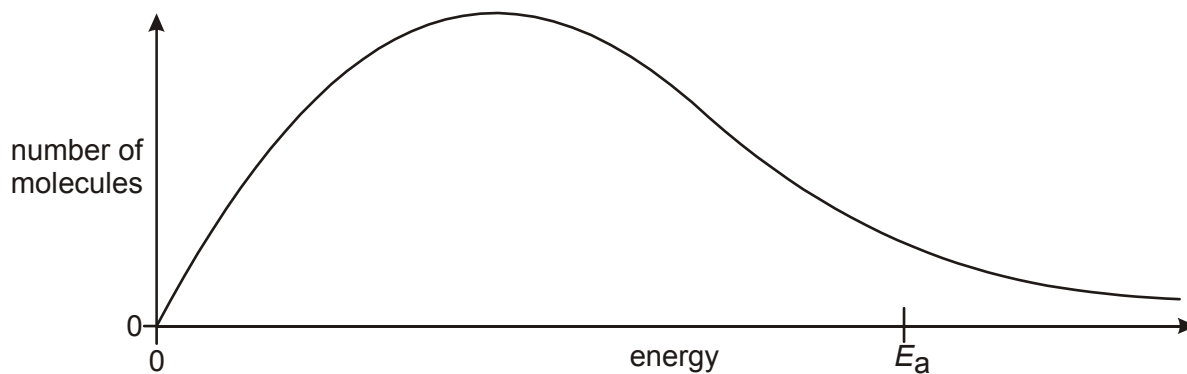
(iii) A catalyst is added.

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[2]

[Total 8 marks]

5. The diagram below shows the energy distribution of molecules at a particular temperature.  $E_a$  represents the activation energy of the reaction.



(i) On the diagram, draw a second curve to represent the energy distribution of the same number of molecules at a higher temperature.

[2]

- (ii) Using your completed diagram, explain how an increase in temperature causes the rate of reaction to increase.

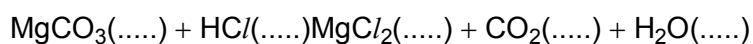
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[2]

[Total 4 marks]

6. A group of students investigated the effect of concentration on the rate of a reaction. They used the reaction between magnesium carbonate and dilute hydrochloric acid and measured the rate at which the gas was collected.

- (a) (i) An incomplete equation for this reaction is given below. Complete the equation by balancing it and inserting state symbols.

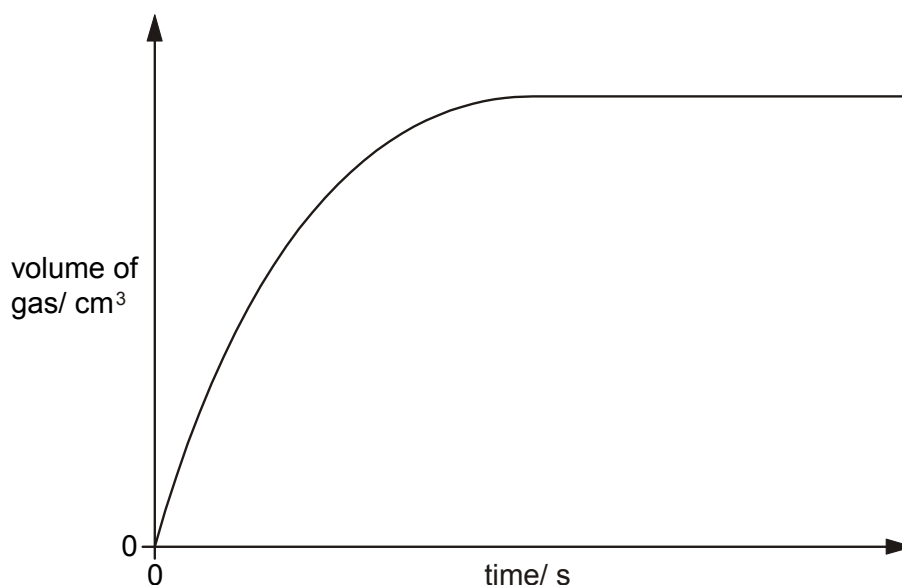


[1]

- (ii) Write the ionic equation for this reaction.

[1]

- (b) The students added dilute hydrochloric acid to some magnesium carbonate. The students collected the gas and measured the volume, at regular intervals, until after the reaction was complete. They then plotted a graph of their results.



Use collision theory to explain the changes in the rate of the reaction as it proceeds.

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[3]

(c) The students repeated the experiment using a weak acid instead of hydrochloric acid.

Assume the concentration of both acids and all other conditions are the same.

(i) On the axes in (b), sketch the graph the students obtained from this experiment.

[2]

(ii) State and explain what effect changing the acid has on the rate of the reaction.

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[2]

[Total 9 marks]

7. Esters are used as flavourings. They are made by a reversible reaction between a carboxylic acid and an alcohol.



(a) Give **two** features of a reversible reaction, when a dynamic equilibrium has been set up.

- 1 .....
- .....
- 2 .....
- .....

[2]

(b) The production of esters is catalysed homogeneously by the presence of acids.

(i) What is meant by a catalyst?

- .....
- .....
- .....
- .....

[1]

(ii) What is meant by homogeneous?

- .....
- .....

[1]

(iii) Using the fact that acids are needed to catalyse this reaction, deduce the formula of the ion that acts as the catalyst.

- .....

[1]

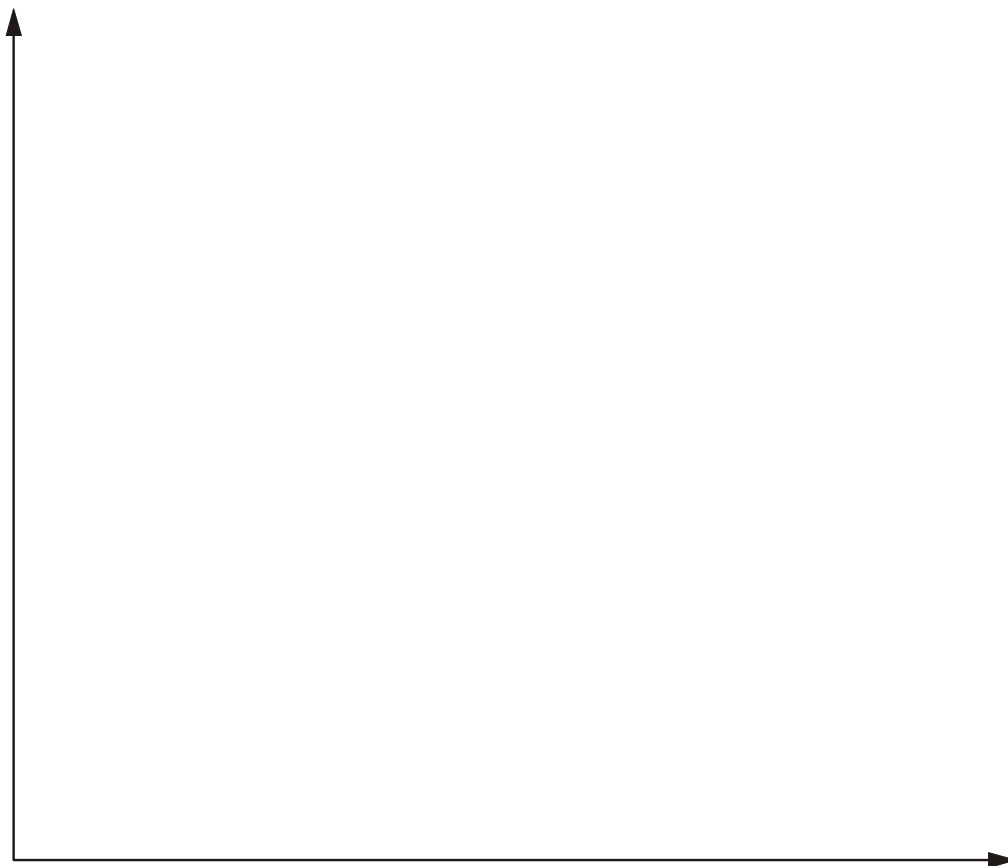
(iv) Catalysts do **not** affect the position of an equilibrium. Explain why not.

- .....
- .....

[1]

[Total 6 marks]

8. (i) On the axes below, draw and label the Boltzmann distribution to show the energies of molecules in a gas at a fixed temperature.



[2]

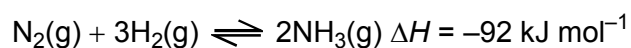
- (ii) Use the graph to explain the effect of a catalyst on the rate of a reaction.

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[2]

[Total 4 marks]

9. Ammonia, NH<sub>3</sub>, is made industrially by the Haber process. This is an equilibrium reaction.



- (a) State the pressure and temperature that are used in the Haber process.

*pressure* .....

*temperature* .....

[2]



- (b) Describe and explain why these conditions are a compromise between rate and equilibrium.

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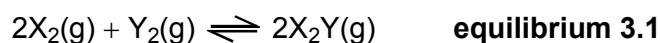
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[9]

[Total 11 marks]

10. Many industrial processes, used to manufacture important chemicals, involve equilibrium reactions. Chemists use their understanding of rates of reaction and of yields at equilibrium to find the most economic conditions for the reactions.

Chemists were investigating the production of a chemical, X<sub>2</sub>Y, that could be formed from X<sub>2</sub> and Y<sub>2</sub> as shown in **equilibrium 3.1** below.



- (a) State le Chatelier's principle.

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[2]

(b) State and explain the effect on **equilibrium 3.1** of a **decrease** in pressure on:

(i) the equilibrium position of the reaction,

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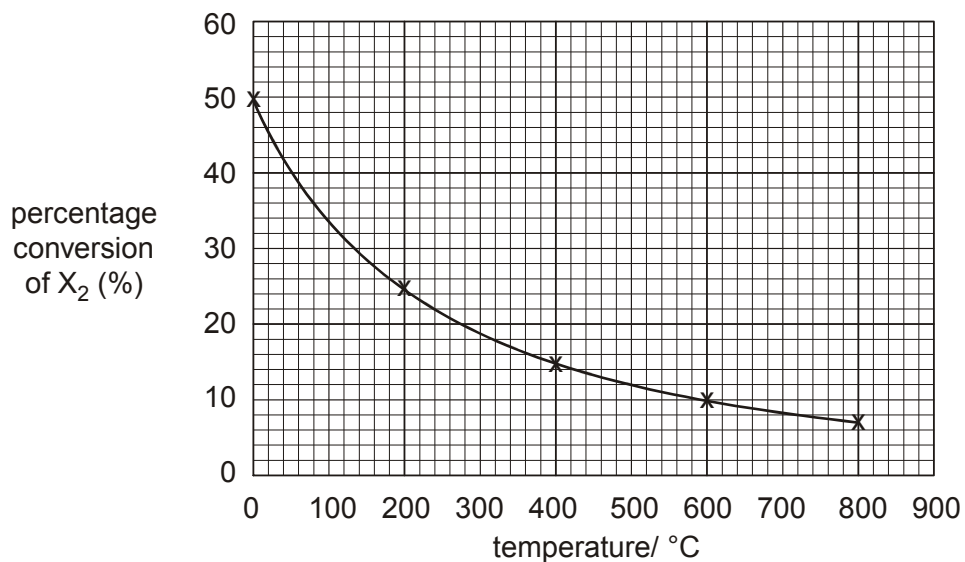
[2]

(ii) the rate of the reaction.

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[2]

(c) The chemists measured the percentage conversion of  $X_2$  at various temperatures. The results are shown in the graph below.



(i) Use the graph to predict the percentage conversion at 350 °C.

answer = .....%

[1]

- (ii) The forward reaction in **equilibrium 3.1** is exothermic. Explain how the graph supports this statement.

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[2]

- (d) The chemists decided to use a catalyst in the process. State, and explain, the effect of using a catalyst on:

- (i) the rate of conversion of  $X_2$  and  $Y_2$  into  $X_2Y$ ,

.....  
.....

[2]

- (ii) the percentage conversion at equilibrium of  $X_2$  and  $Y_2$  into  $X_2Y$ .

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[2]

[Total 13 marks]

- 11.** The Boltzmann distribution can be used to show the effect of a change in temperature on the rate of a reaction.

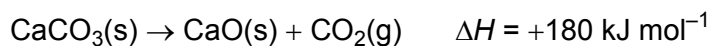
- Draw a labelled Boltzmann distribution diagram.
- Explain the essential features of your diagram.
- Using your diagram, explain how an increase in temperature affects the rate of a reaction.

[Total 9 marks]

12. Limestone contains calcium carbonate, CaCO<sub>3</sub>.

Limestone is an important source of commercially important chemicals such as lime, calcium oxide, CaO.

- (a) If calcium carbonate is heated strongly in an open container, it decomposes according to the equation below.



Suggest **two** reasons why it is necessary to heat the calcium carbonate strongly to achieve decomposition.

1 .....

2 .....

[2]

- (b) Another sample of calcium carbonate was placed in a closed container before being heated strongly. This allows an equilibrium to be set up. This equilibrium is shown below.



- (i) What can you say about the rates of the forward and reverse reactions when the calcium carbonate starts to decompose?

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[1]

- (ii) What can you say about the rates of the forward and reverse reactions when the equilibrium has been established?

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[1]

- (iii) A valve allowed some of the carbon dioxide to escape.

State and explain what happens to the composition of the mixture in the container.

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[3]

[Total 7 marks]

13. A chemical C is made by reacting chemical A with chemical B in a reversible reaction. A, B and C are all gases under the reaction conditions.

Research chemists wanted to know the optimum conditions to use in the manufacture of C. They carried out a series of reactions under different conditions of temperature and pressure. The percentage conversion of A at equilibrium is shown in the table below.

pressure / MPa	temperature / °C	% A converted
10	350	8
	450	12
	550	16
20	350	11
	450	21
	550	29
40	350	18
	450	
	550	49

- (a) Suggest the percentage of A that is converted at 450 °C and 40MPa.

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[1]

- (b) (i) Use the data in the table above to state the effect of increasing pressure on the percentage of **A** converted.

.....

[1]

- (ii) What can be deduced, from this change, about the total number of moles of reactants **A** and **B** compared with the number of moles of product **C** in the equation for the reaction? Explain how you reached your conclusion.

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[2]

- (c) Use the data in the table to deduce whether the reaction between **A** and **B** is exothermic or endothermic. Explain how you reached your conclusion.

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[2]

- (d) It was found necessary to use a catalyst in the production of **C**.

- (i) What is meant by a *catalyst*?

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[2]

- (ii) Suggest and explain **two** reasons why catalysts are used in industrial processes.

1 .....

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2 .....

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[2]

- (e) Conditions were used that should have given a conversion of **A** of 39%. In the manufacture, using these conditions, it was found that only 20% conversion was achieved.

Suggest why the conversion was much less than theory suggested.

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[1]

- (f) Give **two** economically important processes that use catalysts.

process 1 .....

catalyst used in process 1 .....

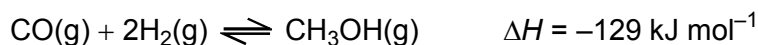
process 2 .....

catalyst used in process 2 .....

[2]

[Total 13 marks]

- 14.** Methanol can be used as a fuel or as the feedstock for a variety of organic compounds. It is manufactured from carbon monoxide and hydrogen.



- (i) Describe and explain how the composition of the equilibrium mixture is affected by increasing the temperature

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increasing the pressure in the reaction.

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[4]

- (ii) Describe and explain the effect of increasing the pressure on the **rate** of reaction.

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[2]

- (iii) The reaction is carried out by passing gaseous reactants over a transition metal catalyst.

Name this type of catalysis.

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[1]

- (iv) Suggest and explain the effect of a catalyst on the equilibrium position.

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[2]

[Total 9 marks]

- 15.** (a) A group of students were considering the factors that affect the rate of a chemical reaction. One of the students wrote the following.

The rate of a chemical reaction increases as the temperature is increased because there are more collisions.

Discuss to what extent this statement is true and describe any other factors that should be considered when looking at the effect of temperature on rate of reaction.

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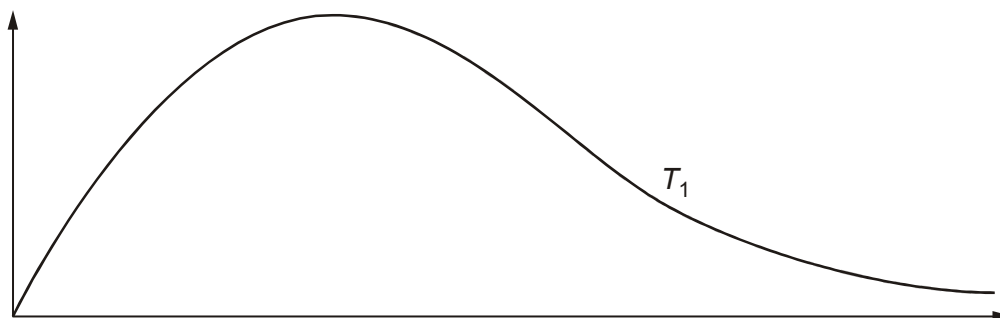
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[5]



(b) The students drew a Boltzmann distribution for a gas at temperature  $T_1$ .

(i) Label the axes on the students' diagram below.



[2]

(ii) Sketch, on the diagram, the distribution that would be obtained at a **lower** temperature,  $T_2$ . Label this line  $T_2$ .

[2]

[Total 9 marks]

16. Part of the manufacture of ammonia involves the equilibrium below.



State le Chatelier's principle.

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[Total 2 marks]

7. A mixture of  $\text{N}_2$  and  $\text{H}_2$  was made and left to reach equilibrium.

Explain how the following changes would affect the **time taken** to reach equilibrium.

(i) use of a catalyst

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[2]

(ii) a higher temperature

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.....  
.....

[2]

(iii) a lower pressure

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.....  
.....

[2]

[Total 6 marks]

18. A mixture of N<sub>2</sub> and H<sub>2</sub> was left until it had reached equilibrium as shown below.



At that stage, N<sub>2</sub>, H<sub>2</sub> and NH<sub>3</sub> were present in the equilibrium mixture.

Explain how the following changes would affect the **amounts** of N<sub>2</sub>, H<sub>2</sub> and NH<sub>3</sub> present in the equilibrium mixture.

(i) use of a catalyst

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.....

[1]

(ii) a higher temperature

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[2]

(iii) a lower pressure

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[2]

[Total 5 marks]

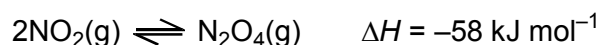
19. This question is concerned with equilibria that exist between oxides of nitrogen.

State Le Chatelier's principle.

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[Total 2 marks]

20. Nitrogen dioxide, NO<sub>2</sub>, is a brown gas whilst dinitrogen tetroxide, N<sub>2</sub>O<sub>4</sub>, is a colourless gas. The following equilibrium between these two gases was set up.



Describe, and explain, what you would see after the following changes have been made and the system allowed to reach equilibrium again.

(i) The temperature is increased.

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[3]

(ii) The pressure is increased.

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[3]

[Total 6 marks]

21. What is a catalyst?

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[Total 2 marks]

22. State le Chatelier's principle.

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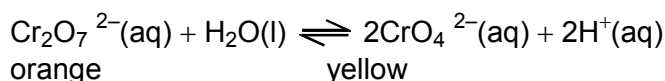
[Total 2 marks]

23. State **two** characteristics of a dynamic equilibrium.

- 1 .....  
2 .....

[Total 2 marks]

24. The following equation represents an equilibrium reaction.

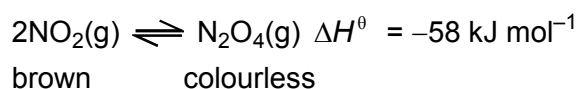


Use le Chatelier's principle to describe and explain the colour change (if any) that might take place when dilute HCl(aq) is added to a solution containing  $\text{K}_2\text{CrO}_4(\text{aq})$ .

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[Total 2 marks]

25. The following equation represents another equilibrium reaction.



Use le Chatelier's principle to describe and explain the colour change (if any) that might take place when

(i) a mixture of  $\text{NO}_2(\text{g})$  and  $\text{N}_2\text{O}_4(\text{g})$  is compressed at constant temperature,

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[2]

(ii) a mixture of  $\text{NO}_2(\text{g})$  and  $\text{N}_2\text{O}_4(\text{g})$  is heated at constant pressure.

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[2]

[Total 4 marks]

26. In this question, one mark is available for the quality of written communication.

What effect does a catalyst have on the rate of a reaction, and how does it achieve this effect?

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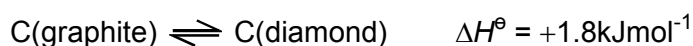
[4]

Quality of Written Communication [1]

[Total 5 marks]

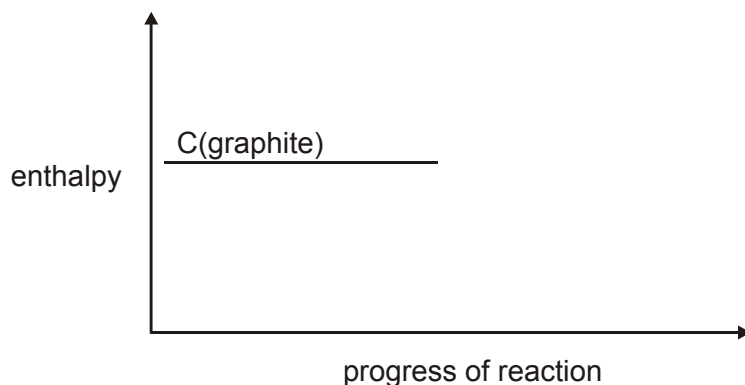
27. Diamond and graphite are two allotropes of carbon. Allotropes are different forms of the same element. Diamonds are made industrially from the much cheaper graphite.

Under high pressure the following equilibrium exists.



substance	Density / $\text{gem}^{-3}$
graphite	2.25
diamond	3.51

(a) Complete the following enthalpy profile diagram for the conversion of graphite into diamond, labelling  $\Delta H^\ominus$ .



[2]

- (b) Suggest which allotrope of carbon is thermodynamically more stable. Give a reason for your choice.

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 .....

[1]

- (c) In which allotrope do the carbon atoms take up less space? Give a reason for your choice.

.....  
 .....

[1]

- (d) State Le Chatelier's principle.

.....  
 .....

[2]

- (e) Use Le Chatelier's principle and the information given at the start of the question to deduce the likely conditions of pressure and temperature needed to turn graphite into diamond. Explain your answer.

pressure .....

.....  
 .....

[2]

temperature .....

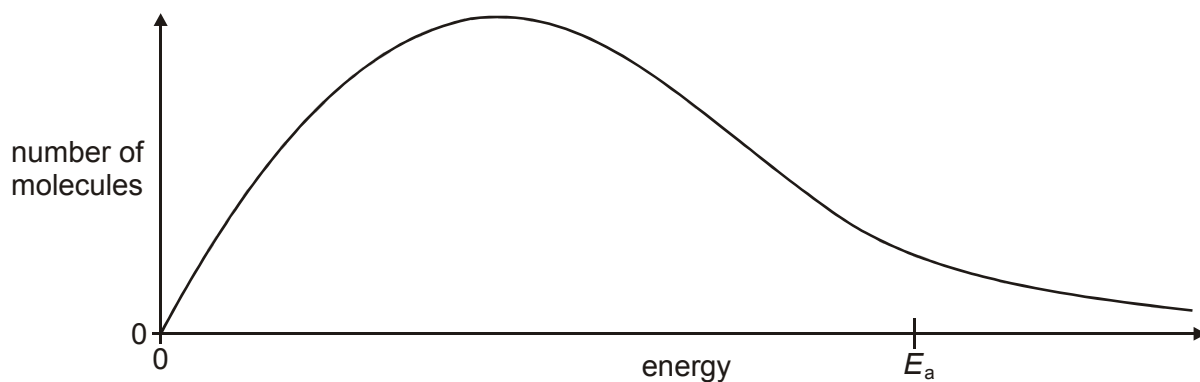
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[2]

[Total 10 marks]

28. The diagram below shows the energy distribution of reactant molecules at a particular temperature.  $E_a$  represents the activation energy of the reaction.



- (i) On the diagram, draw a second curve to represent the energy distribution of the same number of molecules at a higher temperature.

[2]

- (ii) Use your completed diagram to explain how an increase in temperature can cause an increase in the rate of a reaction.

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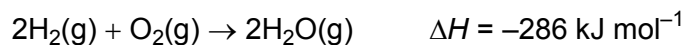
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[2]

[Total 4 marks]

29. The rate of the reaction between hydrogen and oxygen depends on the pressure as well as the temperature.



- (i) Describe and explain the effect of increasing the pressure on the **rate** of this reaction.

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[2]

- (ii) A sudden rapid increase in the rate of a reaction causes an explosion to occur.

Suggest why highly exothermic reactions such as this one are more likely to explode than other reactions.

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[2]

[Total 4 marks]