Chemistry

Chemical Monitoring and Management

New Revised Edition

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Science Press

Contents

Use the table of contents to record your progress through this book. As you complete each topic, write the date completed, then tick one of the three remaining columns to guide your revision for later. The column headers use the following codes:

?? = Don't understand this very well at all. RR = Need to revise this. OK = Know this.

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Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory sections of the syllabus, along with questions and answers.

It is envisaged this book will be useful in class for both initial understanding and revision, while the more traditional textbook can remain at home for more detailed analysis.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style and use the verbs specified by the Board of Studies so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions, including multiple choice and free response questions. These cover every aspect of the topic, and are useful for revision and exam practice. Marking guidelines are supplied where appropriate.

Verbs To Watch

When you are answering questions in this book, your textbook or any examinations, make sure you answer what the question is asking. To do this you will have to know what each of the terms below means – they dictate what sort of an answer is required. It is essential that you learn their meanings as required by the Board of Studies. Your exam answers will be marked according to what these terms indicate your answer should be saying.

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Identify components and the relationships among them, draw out and relate implications.

apply Use, utilise, employ in a particular situation.

appreciate Make a judgement about the value of something.

assess Make a judgement of value, quality, outcomes, results or size.

calculate Determine from given facts, figures or information.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

compare Show how things are similar or different.

construct Make, build, put together items or arguments.

contrast Show how things are different or opposite.

critically (analyse/evaluate) Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to an analysis or evaluation.

deduce Draw conclusions.

define State the meaning of and identify essential qualities.

demonstrate Show by example.

describe Provide characteristics and features.

discuss Identify issues and provide points for and against.

distinguish Recognise or note/indicate as being distinct or different from, note difference between things.

evaluate Make a judgement based on criteria.

examine Inquire into.

explain Relate cause and effect, make the relationship between things evident, provide why and/or how.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

outline Sketch in general terms; indicate the main features.

predict Suggest what may happen based on available information.

propose Put forward a point of view, idea, argument or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

recommend Provide reasons in favour.

recount Retell a series of events.

summarise Express concisely the relevant details.

synthesise Put together various elements to make a whole.

1 The Work of Chemists

In industry, chemists monitor the reactants and products of reactions and manage the conditions under which reactions occur. They may have a university degree in chemistry, engineering or science, or TAFE qualifications. The work of chemists includes:

- quality control to ensure the purity of reactants and products
- monitoring equipment
- monitoring and minimising waste products and resulting pollution of the environment
- ensuring the process is efficient, producing maximum yield of product and minimal waste
- investigating improvements to plant performance
- ensuring the safety of workers.

To do this they will be involved in such activities as:

- analysis of raw materials and quality control of the final products, using techniques such as chromatography and spectroscopy
- stoichiometric calculations.

Chemists work together with chemical, mechanical and electrical engineers, laboratory technicians, skilled tradespeople and operators to ensure that a plant runs economically and safely.

For You To Do

1. Chemical occupations can be classified in a number of ways. One possible classification is shown in Table 1.1.

Table 1.1 Branches of chemistry.

Branches	Examples of work carried out
Basic research	
Applied research and development	
Chemical manufacturing	
Analytical chemistry	
Biochemistry	
Chemical engineering	
Physical chemistry	

   (a) For each of the branches listed, suggest examples of the tasks that would be carried out by chemists working in that field.
   (b) Choose one of the branches listed in Table 1.1. From your studies, identify and explain a chemical principle that a chemist working in that area would use.

2. Each of the branches of chemistry listed in Question 1 can be subdivided extensively. For example, the chemical manufacturing industries could be subdivided as shown in Table 1.2. Complete this table by identifying a range of products that could be manufactured by each industrial division.

Table 1.2 Chemical manufacturing industries.

Chemical manufacturing industries	Substances manufactured
Plastics, materials and synthetics	
Soaps and cleaners	
Industrial organic chemicals	
Industrial inorganic chemicals	
Paints and allied products	

3. Investigate two practicing scientists, one male and one female, working in any area of chemistry. For each of these scientists, find information about:
   (a) Their qualifications and training.
   (b) The area they work in – the industry and branch of science this involves.
   (c) The type of work they do.
   (You will find plenty of references on the Internet if you search using terms such as 'research chemist'. If you do not have access to the Internet, try scientific journals, e.g. *New Scientist*.)
4. Three scientists from the USA and Japan, Professors MacDiarmid, Shirakawa and Heeger, were awarded the Nobel Prize in Chemistry in 2000 for showing how plastic can be made to conduct electricity.
   (a) Research the role that these chemists played in this discovery.
   (b) Propose ways in which this discovery may be able to benefit society.
   (c) Identify a technological development that would have contributed to, or been essential for, this discovery.
5. Identify another recent discovery in chemistry. (Useful sources include the CSIRO, articles about Nobel Prize winners and scientific magazines.)
   (a) Outline the role played by chemists involved in this discovery.
   (b) Suggest ways in which this discovery may be able to benefit society.
   (c) Suggest a technological development that would have contributed to, or been essential for, this discovery.

6. The following two advertisements appeared recently in a national newspaper.

1. Research Assistants in Biology and Chemistry

You will join a research team with a private research company focusing on the discovery of new pharmaceuticals.

The **biologist** will be isolating micro-organisms and testing microbial extracts for biological activity.

The **chemist** will assist in the isolation of compounds from the microbial extracts.

Experience in microbiological techniques would be an advantage and also knowledge of computer spreadsheet and word processing software.

Applicants should have an Advanced Technical Certificate or an Associate Diploma.

Send your application with the names of at least two referees to the Administration Officer.

2. Chemist – Healthcare, Sydney

This company has the reputation of being one of the major manufacturers and suppliers of healthcare products throughout Australia.

The opportunity: Healthcare is offering a role for an experienced chemist in finished product testing, method development and troubleshooting.

Responsibilities will include:

- management of the stability testing programs
- providing technical expertise to R and D and marketing on the development of new products
- development and validation of new testing methodologies
- meeting testing deadlines.

Skills and experience required:

- tertiary qualification in chemistry
- minimum of three years experience in pharmaceutical/ healthcare environment
- well developed technical, communication, organisational and time management skills
- in-depth knowledge of regulations
- demonstrated leadership skills.

If attention to detail combined with customer responsiveness is your specialty and you meet these requirements we need to hear from you.

This position reports directly to the Quality Control Manager.

Applications to the Human Resources Manager.

(a) For each of these advertisements, identify:
  (i) The qualifications and attributes a successful applicant would need.
  (ii) Examples of the tasks that would be carried out by chemists working in that field.

(b) Outline two questions you would ask each applicant if you were on the panel conducting interviews for this position.

(c) Your teacher may ask you to role-play a job interview or to find other job applications.

7. For each of the chemical principles listed below, identify an area of chemistry in which that principle could be used.
  (a) A chemical reaction occurs when a new substance is formed.
  (b) Polymers consist of chains of monomers.
  (c) A mixture of liquids can be separated into its components by fractional distillation.
  (d) A catalyst is used to control the rate of a chemical reaction.
  (e) The oxidation state of species can be accounted for in terms of their loss or gain of electrons.
  (f) Radiation is emitted from unstable elements.

8. Some chemical reactions will form different products under different conditions. For example, with excess oxygen, the components of petrol (such as octane) will undergo complete combustion.
  (a) Write an equation to show the complete combustion of octane.
  (b) With reduced oxygen supplies, combustion may be incomplete, thus producing different products and also releasing less energy per mole of octane. Write equations to show the incomplete combustion of octane to produce:
    (i) Carbon monoxide.
    (ii) Carbon.
  (c) In the industrial combustion of fuels and in the internal combustion engine, the fuel-to-air ratio must be monitored to ensure relatively complete combustion. Explain why the complete combustion of substances such as octane is preferred to incomplete combustion.
  (d) Justify the need to monitor the composition of motor vehicle exhaust gases.

9. Using examples from topics you have already covered in this course, outline some examples of work that could be done by chemists in the fields of:
  (a) Organic chemistry.
  (b) Inorganic chemistry.

10. As you study this module, collect any newspaper or magazine articles and record any television coverage of events relevant to chemistry. For each of these, summarise:
  (a) The chemistry that needs to be understood to fully understand the media coverage.
  (b) The area of chemistry to which this news item is relevant.
  (c) Possible impacts of the chemistry in this item on society and the environment.
  (d) Any new technologies described in this news item.
  (e) The relevance of this item to the availability of career opportunities in chemistry.

2 Equilibrium and Rates of Reaction

Chemical manufacturing processes need to be **monitored and managed** so as to maximise production and ensure quality control. One such process is the Haber process, which manufactures ammonia from the gases nitrogen and hydrogen. Before you study this process, you should revise the work you have already done on exothermic reactions, rates of reactions, equilibrium reactions and Le Châtelier's principle. Some of the main points you should remember follow.

Reaction rates depend on the rate and force of collisions between particles (atoms, ions or molecules) of the reactants. The more frequently they collide, the faster the rate of reaction. This is influenced by:

- concentration of reactants
- temperature
- presence of catalysts
- particle size
- pressure (if gases are involved).

Chemical reactions can be **endothermic** (absorb heat from the surroundings) – for example photosynthesis, thermal decomposition – or **exothermic** (release heat) – for example combustion, neutralisation reactions and respiration.

An **equilibrium reaction** is reversible; it proceeds in both forward and reverse directions at the same time. The characteristics of a chemical system at equilibrium are:

- It is a closed system: no matter or energy enters or leaves the system.
- Macroscopic properties are constant, for example state, colour, temperature, pressure and concentration.
- Continual microscopic change occurs between reactants and products.
- Rate of forward reaction = rate of backward (reverse) reaction.
- Concentrations of reactants and products stay constant (but not necessarily equal to each other).

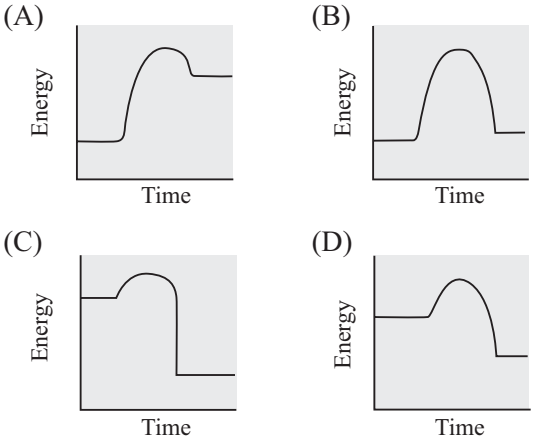
Equilibrium can be disturbed by:

- changing the concentration (by adding or removing any reactant or product)
- changing the temperature
- changing the pressure or volume if any reactants or products are gases.

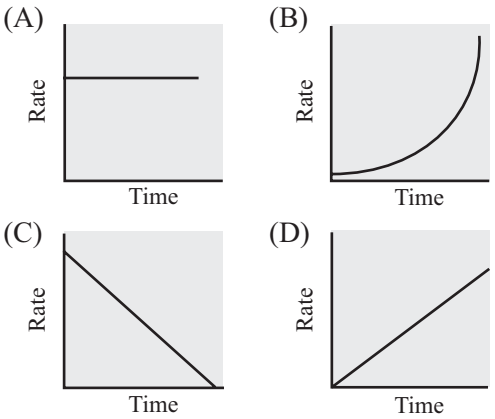
Whenever an equilibrium position is disturbed, the system always tries to reduce the amount of change. This is called **Le Châtelier's principle**. Le Châtelier's principle states that if a system in equilibrium is changed, the system adjusts itself to minimise the change.

For You To Do

1. Which of the following is an example of an exothermic chemical reaction?
   (A) Decomposition of calcium carbonate.
   (B) Combustion of sodium metal.
   (C) Fractional distillation of petroleum.
   (D) Condensation of water.
2. For which of the following reactions would decreasing the pressure increase the yield of product C?
   (A) $A(g) + B(g) \rightleftharpoons C(g) + D(g)$
   (B) $A(aq) + B(aq) \rightleftharpoons C(aq) + D(aq)$
   (C) $A(aq) + B(g) \rightleftharpoons C(g) + D(g)$
   (D) $A(g) + B(g) \rightleftharpoons C(g) + D(aq)$
3. In a system at equilibrium:
   (A) The rate of the forward reaction equals the rate of the reverse reaction.
   (B) The concentration of reactants equals the concentration of products.
   (C) All concentrations are equal.
   (D) The addition of a catalyst increases the yield of a product.
4. Consider the four energy profiles shown below. Identify the one that is exothermic and most likely to go to completion.

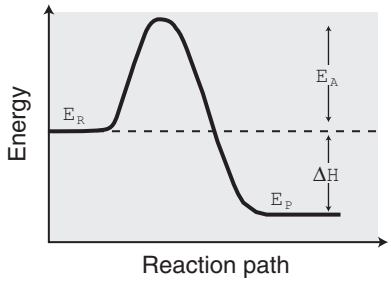


5. The rates of many chemical reactions are initially fast and then slow down as reactants are used up. Which graph best illustrates this?



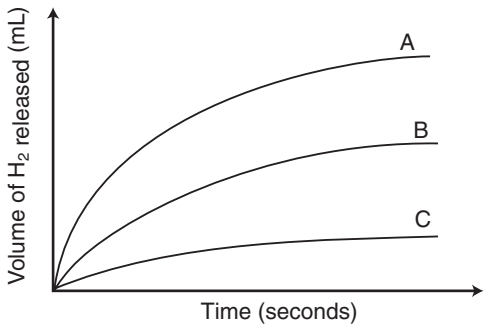
6. Chemical reactions can be exothermic or endothermic.
   (a) Distinguish between an exothermic reaction and an endothermic reaction.
   (b) We can show the changes in energy level for reactions with energy profiles such as that shown below for an exothermic reaction (Figure 2.1). In this profile, the following symbols are used:
   E_R = energy of reactants
   E_P = energy of products
   E_A = activation energy (the energy needed to start the reaction)
   ΔH = change in enthalpy

Figure 2.1 Reaction path of exothermic reaction.



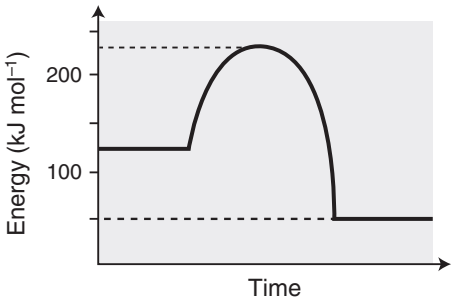
   Draw a similar labelled diagram to show energy changes in an endothermic reaction.
7. State whether each of the following reactions is endothermic or exothermic.
   (a) A + B → C + D + heat
   (b) A + B + heat → C + D
   (c) A + B → C + D, ΔH = negative
   (d) A + B → C + D, ΔH = positive
8. Outline four factors that can influence the rate of chemical reactions.
9. A student carried out an experiment to compare the rate of reaction between magnesium and hydrochloric acid using three different concentrations of acid. To assess the rate of reaction she measured the volume of hydrogen released at intervals. From the results she drew the graphs shown in Figure 2.2.

Figure 2.2 Volume of hydrogen released.



   The concentrations used were 0.5, 1.3 and 2.0 mol L^{-1}.
   (a) Which experiment, A, B or C, shows the greatest initial rate of reaction?
   (b) Which graph would have been based on the results obtained from using the 2 mol L^{-1} acid? Justify your answer.
   (c) Write a conclusion for this experiment.
10. In the experiment described in Question 9, identify:
   (a) Variables that need to be kept constant.
   (b) The dependent variable.
   (c) The independent variable.
11. Figure 2.3 shows an energy profile for a combustion reaction.

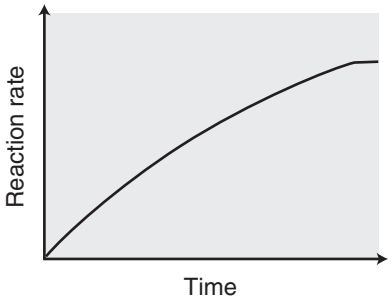
Figure 2.3 Energy profile for combustion reaction.



   (a) Is this reaction exothermic or endothermic? Explain.
   (b) For this reaction state the value of the:
      (i) Activation energy.
      (ii) Enthalpy change.
12. Explain what is meant by each of the following.
   (a) A reversible reaction.
   (b) Le Châtelier's principle.
   (c) An equilibrium reaction.
   (d) A catalyst.
13. For the equilibrium reaction A + B ⇌ C + D + heat what would be the effect of the following?
   (a) Increasing the temperature.
   (b) Lowering the temperature.
14. For the equilibrium reaction A + B + heat ⇌ C + D what would be the effect of the following?
   (a) Increasing the temperature.
   (b) Lowering the temperature.
15. For the equilibrium reaction:
   A(g) + B(g) ⇌ C(aq) + D(g)
   the reaction in the forward direction (as written) is exothermic. What effect would the following changes have on the equilibrium position?
   (a) Increase the concentration of A.
   (b) Increase the concentration of D.
   (c) Remove D as it forms.
   (d) Increase the pressure.
   (e) Add a catalyst.
   (f) Increase the temperature.

16. For the following reaction, list ways in which you could increase the yield of D.
$A(aq) + B(aq) \rightleftharpoons C(aq) + D(aq) + heat$
17. Describe the characteristics of a system at equilibrium.
18. Figure 2.4 shows reaction rates for the uncatalysed reaction:
$H_2(g) + S(s) \rightleftharpoons H_2S(g)$

Figure 2.4 Reaction rate for uncatalysed reaction.



On this graph show the effect, on reaction rate, of adding a catalyst.

19. One example of an equilibrium reaction is the decomposition of dinitrogen tetroxide. At room temperature, dinitrogen tetroxide (N_2O_4) is a colourless gas (boiling point 21°C) that decomposes to form the dark brown gas nitrogen dioxide (NO_2). At the same time, some of the nitrogen dioxide re-forms into dinitrogen tetroxide.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$
Colourless dark brown

If this is in a sealed container and kept at a constant temperature, equilibrium will eventually be reached, the colour of the mixture at equilibrium depending on the amount of each gas present.
   (a) If you were given a sealed jar containing dinitrogen tetroxide, what observation would tell you that it was decomposing to nitrogen dioxide?
   (b) Explain how you could determine, from observing only, that the mixture of dinitrogen tetroxide and nitrogen dioxide, in your sealed container, was at equilibrium.
   (c) Describe what would be happening, at the molecular level, inside your container at equilibrium.
20. Changing conditions such as temperature will change the equilibrium position. Eventually the system reaches a new equilibrium at the new temperature. For any particular temperature, the percentage of each gas in the mixture will always be the same.

Consider the equilibrium:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$
Colourless dark brown

At 21°C, the mixture will contain about 16% nitrogen dioxide and it will look light brown; at 100°C, the mixture will contain about 90% nitrogen dioxide and it will look dark brown.
Based on this information, deduce whether the reaction as stated is exothermic or endothermic. Explain your answer.

21. The thermal decomposition of calcium carbonate in a closed container is an equilibrium system.
$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
   (a) Explain the meaning of thermal decomposition.
   (b) Would this system still be in equilibrium if the reaction were carried out in an open container? Explain.
   (c) Describe any effect on the equilibrium position for this reaction if the carbon dioxide were removed.
   (d) Name a chemical that could be used to absorb the carbon dioxide.
   (e) Describe any effect on the equilibrium of adding more calcium carbonate.
22. Weak acids in solution form an equilibrium system, for example:
$CH_3COOH(l) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$
Describe the effect on the equilibrium position for this reaction in each of the following cases:
   (a) Sodium acetate solution is added.
   (b) Sodium hydroxide is added.
23. Check your knowledge with this quick quiz.
   (a) A reaction that releases energy to the environment is said to be _____.
   (b) A reaction that proceeds in both directions at the same time is said to be _____.
   (c) What do we call a substance that varies the rate of a chemical reaction without being used up by the reaction?
   (d) In an equilibrium system, observable properties (e.g. colour) are referred to as _____.
   (e) At equilibrium, the rate of the forward reaction is equal to the rate of the _____.
   (f) Increasing the number of gas particles in a sealed container will (increase/decrease) the pressure.
   (g) At equilibrium the concentration of reactants and products _____.
   (h) Removing a product as it forms from an equilibrium vessel will (increase/decrease) the yield of products.