Course

# CHE-5062-2

## Chemistry: Kinetics and Equilibrium

Chemistry

## INTRODUCTION

The course entitled *Chemistry: Kinetics and Equilibrium* is aimed at enabling adult learners to function effectively in situations from the *Research* and *Expertise* families that involve elements of kinetics and chemical equilibrium.

Adult learners enrolled in this course study phenomena or technological applications related to the reaction rate of a chemical reaction or to chemical equilibrium, and look for answers or solutions to problems involving them. They thus acquire knowledge about rate law, equilibrium constants, factors that influence the reaction rate and the state of equilibrium, Le Châtelier's principle and the relationship between the pH and the molar concentration of hydronium and hydroxide ions. This knowledge helps them to explain the factors associated with certain phenomena, for example, control of blood pH or enzyme reactions, and enables them to understand how a technological application, such as swimming pool maintenance products and biodegradable plastics, works. In addition, as the experimental method and modelling occupy a central place in the development of competencies and the construction of knowledge related to the concepts in the course, adult learners carry out several laboratory activities designed to help them autonomously exercise the specific skills related to techniques and methods.

By the end of this course, in *Research* and *Expertise* situations, adult learners will be able to:

- ✓ carry out an investigative process that includes experimentation to solve a problem related to chemical kinetics or chemical equilibrium
- ✓ analyze a phenomenon or technological application involving the factors that influence the reaction rate or the state of equilibrium
- ✓ predict the effect of modifying a parameter on the rate of a chemical reaction or on the state of equilibrium of a chemical system
- ✓ follow an experimental protocol that they have prepared; one which involves chemical kinetics or the state of equilibrium of a chemical system
- ✓ write a laboratory report on chemical kinetics or the state of equilibrium of a chemical system

## SUBJECT-SPECIFIC COMPETENCIES

The following table lists, for each competency, the key features studied in the course. The manifestations of the key features are presented in Appendix 4.

| Competency 1<br>Seeks answers or solutions to problems involving chemistry | Competency 2<br>Makes the most of his/her knowledge of chemistry | Competency 3<br>Communicates ideas relating to questions involving chemistry, using the languages associated with science and technology |
|---|---|---|
| ▪ Defines a problem<br>▪ Develops a plan of action<br>▪ Carries out the plan of action<br>▪ Analyzes his/her results | ▪ Identifies the principles of chemistry underlying a phenomenon or application<br>▪ Analyzes the principles of chemistry underlying a phenomenon or application<br>▪ Explains a phenomenon or an application from the standpoint of chemistry | ▪ Interprets scientific or technological messages<br>▪ Produces scientific or technological messages |

## PROCESSES

The investigative processes enable adult learners to solve problems involving the principles of chemistry, and to study an application or a phenomenon involving kinetics and chemical equilibrium. The following are the steps in an investigative process:

- Define the problem
- Formulate a hypothesis
- Test the hypothesis
- Draw conclusions and communicate

The most appropriate investigative processes for this course are: the observation method, the experimental method and modelling. It is during the step of verifying a hypothesis that these methods become distinguishable. Section 3.5 and Appendixes 1 to 3 present these investigative processes, with their respective characteristics.

In this course, laboratory experiments require adult learners to carry out specific tasks in accordance with the following limitations and instructions.

| Experimental Method | |
|---|---|
| **Steps** | **Tasks** |
| 1. Plans an experiment | The adult learner:<br>- writes up an experimental protocol for chemistry<br>- selects the materials required to do an experiment<br>- identifies the applicable safety rules, the constant parameters and the parameters to be investigated (independent variable, dependent variable) |
| 2. Conducts the experiment | The adult learner:<br>- follows the experimental protocol and adjusts it as required<br>- takes measurements, keeping in mind the factor of experimental error<br>- applies the appropriate safety rules |
| 3. Interprets the results | In writing up a report, the adult learner:<br>- takes significant figures into account when processing the data<br>- analyzes the results<br>- estimates the maximum allowable error due to the user and the environment<br>- discusses the results<br>- writes the conclusion, making connections with the problem in question |

## CROSS-CURRICULAR COMPETENCIES

The cross-curricular competencies supplement the subject-specific competencies. The development of one contributes to the development of the others. Course CHE-5062-2 allows for putting all the cross-curricular competencies into practice. Some of them, indicated in grey shading in the table below, are especially targeted in the sample learning situation presented for the requirements of the course.

| Cross-Curricular Competencies | | | |
|---|---|---|---|
| **Intellectual** | **Communication-Related** | **Personal and Social** | **Methodological** |
| Uses information | Communicates appropriately | Achieves his/her potential | Adopts effective work methods |
| Solves problems | | Cooperates with others | Uses information and communications technologies |
| Exercises critical judgment | | | |
| Uses creativity | | | |

## SUBJECT-SPECIFIC CONTENT

### A) KNOWLEDGE

The compulsory concepts and techniques are presented in the tables in the following two sections.

### 1. Concepts

The knowledge written in italics has been acquired in the science and technology programs and must be mobilized again in this course.

| The Material World | |
|---|---|
| **General concept: Reaction rate**<br>The rate at which reactants are transformed into products depends on several factors (nature of the reactants, concentration, surface area, temperature, catalysts). There are therefore many different ways to speed up or slow down changes in matter.<br>The rate law uses algebraic expressions to compare the rates of various chemical reactions and, in some cases, to calculate their numerical value. The rate law provides a better understanding of the dynamic nature of equilibrium and can be used to express equilibrium constants mathematically. | |
| **COMPULSORY CONCEPTS** | **PREVIOUSLY ACQUIRED KNOWLEDGE** |
| Concentration | • *Describes the effect of variations in the quantity of solute or solvent on a solution's concentration*<br>• *Determines the concentration of an aqueous solution (g/L, percentage, ppm, mol/L)* |
| Stoichiometry | • *Determines the quantities of reactants or products using stoichiometric calculations* |
| **COMPULSORY CONCEPTS** | **KNOWLEDGE TO BE ACQUIRED** |
| Factors that influence the reaction rate: | • Determines experimentally the factors that influence the reaction rate |
| - nature of the reactants | • Explains the effect of the nature of the reactants on the reaction rate |
| - concentration | • Explains the effect of the concentration of the reactants on the reaction rate |
| - surface area | • Explains the effect of the surface area of the reactants on the reaction rate |
| - temperature | • Explains the effect of the temperature of the reactants on the reaction rate |
| - catalysts | • Explains the effect of a catalyst on the reaction rate |
| Rate law | • Describes the relationship between the concentration of the reactants and the reaction rate using algebraic expressions<br>• Determines the effect of a variation in the concentration of a reactant on the reaction rate, using the related algebraic expression |

**General concept: Chemical equilibrium**

Dynamic equilibrium is a state found in many different chemical, physical and biological systems. The qualitative study of the state of equilibrium and the factors that influence it are required to understand many phenomena or applications. Le Châtelier's principle is used, among other things, to predict changes in systems after their conditions have been modified.

Whatever system is being considered, the interpretation and calculation of the equilibrium constant expression (water ionization constant, acidity and alkalinity constants, solubility product constant) can be used to deal with both the qualitative and quantitative aspects of chemical equilibrium. The use of first- and second-degree equations may be necessary.

The water ionization constant is used to understand the interdependency of the molar concentrations of hydronium and hydroxide ions. The pH of aqueous solutions can be calculated by determining either of these molar concentrations and using logarithmic functions. Scientific notation must be mastered.

| COMPULSORY CONCEPTS | PREVIOUSLY ACQUIRED KNOWLEDGE |
|---|---|
| Types of bonds (ionic) | • *Defines an ionic bond as a bond resulting from the gain or loss of electrons*<br>• *Draws a schematic representation of an ionic bond*<br>• *Identifies molecules that have an ionic bond (e.g. NaCl, $NH_4OH$)*<br>• *Associates an ionic bond with an electrolytic substance* |
| Strength of electrolytes | • *Qualitatively associates the strength of an electrolyte with its degree of dissociation* |
| Electrical conductivity | • *Describes the mechanism that allows aqueous solutions to conduct electricity (electrolytic dissolution of a solute, formation of mobile ions)* |
| Acid-base neutralization reaction | • *Gives examples of acid-base neutralization reactions (e.g. adding lime to neutralize the acidity of a lake)*<br>• *Names the products formed during acid-base neutralization (salt and water)*<br>• *Recognizes an acid-base neutralization from its equation* |
| Salts | • *Determines the molecular formula of the salt produced by the neutralization of a given acid and a given base* |
| pH scale | • *Describes the pH scale (acidity, alkalinity, neutrality, increasing and decreasing values)* |
| **COMPULSORY CONCEPTS** | **KNOWLEDGE TO BE ACQUIRED** |
| Factors that influence the state of equilibrium: | • Explains qualitatively the state of dynamic equilibrium |
| - concentration | • Explains the effect of a change in the concentration of a reactant or a product on a system's state of equilibrium |
| - temperature | • Explains the effect of a temperature change on a system's state of equilibrium |
| - pressure | • Explains the effect of a pressure change on a system's state of equilibrium |
| Le Châtelier's principle | • Predicts the direction of the shift in equilibrium of a system following a change in concentration, temperature or pressure<br>• Predicts the effects of the shift in equilibrium of a system on the concentrations of reactants and products |

| **Chemical equilibrium (cont.)** | |
|---|---|
| **COMPULSORY CONCEPTS** | **KNOWLEDGE TO BE ACQUIRED** |
| Equilibrium constant: | |
| - water ionization constant | • Writes the water ionization constant as an algebraic expression<br>• Calculates the molar concentration of hydronium and hydroxide ions, using the water ionization constant at 25°C |
| - acidity and alkalinity constants | • Writes as an algebraic expression the equilibrium constant for the dissociation of an acid or a base<br>• Experimentally determines the acidity or alkalinity constant of a system<br>• Associates the strength of acids and bases with the value of their acidity or alkalinity constant |
| - solubility product constant | • Writes as an algebraic expression the equilibrium constant for the dissociation of various substances in water<br>• Calculates the solubility product constant of a substance<br>• Explains the use of various substances using their solubility product constant (e.g. rapidly dissolving salts have a high constant) |
| Relationship between the pH and the molar concentration of hydronium and hydroxide ions | • Describes the relationship between the pH and the molar concentration of hydronium and hydroxide ions<br>• Applies the relationship between the pH and the molar concentration of hydronium ions ($pH = -\log_{10} [H^+]$) |

## 2. Techniques

The techniques presented here are grouped in two categories. Many of these techniques require the use of instruments or chemicals. Safety and the use of safety equipment must be a constant concern for all those using such techniques.

| In the Laboratory | |
|---|---|
| **TECHNIQUES** | **KNOWLEDGE TO BE ACQUIRED** |
| **Laboratory work** | |
| - Safely using laboratory materials and equipment | • Uses laboratory materials and equipment safely (e.g. allows a hotplate to cool before touching it, uses beaker tongs)<br>• Handles chemicals safely (e.g. uses a spatula and a pipette filler) |
| - Preparing solutions | • Prepares an aqueous solution of a specific concentration given a solid solute<br>• Prepares an aqueous solution of a specific concentration given a concentrated aqueous solution |
| - Collecting samples | • Collects samples appropriately (e.g. sterilizes the container, uses a spatula, refrigerates the sample) |
| **Measurement** | |
| - Checking the reliability, accuracy and sensitivity of measuring instruments | • Takes the same measurement several times to check the reliability of the instrument used<br>• Carries out the required operations to ensure the accuracy of a measuring instrument (e.g. cleans and calibrates a balance, dries a graduated cylinder)<br>• Takes the sensitivity of a measuring instrument into account (e.g. uses a 25-mL graduated cylinder rather than a 100-mL one to measure 18 mL of water) |
| - Interpreting measurement results (significant figures, measurement errors) | • Determines the margin of error attributable to a measuring instrument (e.g. the error in a measurement made using a graduated cylinder is provided by the manufacturer or corresponds to half of the smallest division on the scale)<br>• Estimates measurement errors associated with the user and the environment<br>• Expresses a result with a number of significant figures that takes into account the errors related to the measure (e.g. a measurement between 10.3 and 10.4 cm, taken with a ruler graduated in millimetres, should be expressed as 10.35 cm or 103.5 mm)<br>• Expresses the value of a measurement with its absolute or relative uncertainty (e.g. 24.1 ± 0.1 mL or 24.1 mL ± 0.4%) |

## B) CULTURAL REFERENCES

Cultural references make learning situations more meaningful. The following table presents some of the references related to this course. Learning situations may also draw on other cultural references.

<table>
<tr><th colspan="5">Cultural References</th></tr>
<tr><td>Technical objects, technological systems, processes and products</td><td colspan="4">Kinetics<br>– Combustion rate<br>– Fire protection methods<br>– Catalytic converters<br>– Catalysts and inhibitors<br>– Food additives<br>– Enzyme reactions<br>– Pharmacokinetics (action and elimination of medication)<br>– Biodegradable plastics<br>– Fertilizer dissolution rate<br>– Anti-corrosion surface treatments<br><br>Chemical equilibrium<br>– Household cleaning products<br>– Swimming pool maintenance products<br>– Haber process<br>– Fishkeeping<br>– Control of blood pH<br>– Control of gastric acidity<br>– Impact of human activities on biogeochemical cycles<br>– Biocides (e.g. pesticides, insecticides)<br>– Stratospheric ozone<br>– Physicochemical soil decontamination<br>– Water cycle<br>– Carbon cycle</td></tr>
<tr><th>Area</th><th>Scientists</th><th>Community Resources</th><th>Applications</th><th>Events</th></tr>
<tr><td>The Material World</td><td>James Clerk Maxwell<br>James Prescott Joule<br>Ludwig Boltzmann<br>Svante August Arrhenius<br>J.H. Van’t Hoff<br>Henry-Louis Le Châtelier<br>Fritz Haber<br>Wilhelm Ostwald<br>Alfred Nobel<br>Nicolas Leblanc<br>Ernest Solvay</td><td>Association francophone pour le savoir (ACFAS)<br>Conseil de développement du loisir scientifique (CDLS)<br>National Research Council of Canada (NRC)<br>Chemical Institute of Canada (CIC)<br>International Union of Pure and Applied Chemistry (IUPAC)</td><td></td><td>Science fairs<br>Nobel Prize in Chemistry</td></tr>
</table>

## FAMILIES OF LEARNING SITUATIONS

The learning situations in this course, derived from the *Research* and *Expertise* families, involve kinetics and chemical equilibrium for gases in a closed system as well as aqueous and acid-base solutions. The paragraphs below give examples of tasks that can be assigned to adult learners in such learning situations.

One learning situation involving reaction rates may require that adult learners explain the role of enzymes in digestion. They can then carry out different experiments to validate their explanation.

In a learning situation addressing the factors that could influence the state of equilibrium of a system, adult learners can prepare a procedure for an experiment with the objective of discovering the effect of these factors on the direction of a reaction, carry out the experiment and write a complete report.

In another situation, the adult learner is required to study, understand and explain the factors to be considered in introducing a new species of fish in a balanced aquarium that is already home to a specimen. The adult learner can describe the characteristics of the environment, suggest actions to be taken that take chemical kinetics into consideration, and present the links that connect the external factors and their effects on the state of equilibrium, making sure to provide scientific justification in each case.

In the learning situation described on the following page, the main tasks help adult learners develop the first and third competencies. This situation therefore belongs to the *Research* family.

## BROAD AREAS OF LEARNING

Learning situations are more meaningful for adult learners when their context is connected to the broad areas of learning. The broad areas of learning most readily applicable to the learning situations for the course CHE-5062-2 are *Health and Well-Being*, *Career Planning and Entrepreneurship, Environmental Awareness and Consumer Rights and Responsibilities*, and *Citizenship and Community Life*. The following example reflects the educational aim of the broad area of learning *Environmental Awareness and Consumer Rights and Responsibilities.*

| Broad Areas of Learning |
|---|
| Health and Well-Being |
| Career Planning and Entrepreneurship |
| Environmental Awareness and Consumer Rights and Responsibilities |
| Media Literacy |
| Citizenship and Community Life |

## EXAMPLE OF A LEARNING SITUATION

MANUFACTURING AMMONIA? THAT'S EASY!

Your uncle works for a company that makes ammonia using the Haber process. Knowing that you are taking a chemistry course, he challenges you to explain the process for making ammonia, in terms of temperature and pressure. The only information he gives you is that hydrogen and nitrogen are the reactants. Taking into consideration the means available at your centre, he would also like you to produce a reaction with similar properties to illustrate your explanation.

To meet your uncle's challenge, you first have to determine the chemical equation for manufacturing ammonia on a large scale using the Haber process. You then need to develop an experimental procedure that will allow you to test the effects of temperature, pressure or the concentration of products or reactants on the state of equilibrium of a similar chemical reaction. Finally, you will explain the Haber process, presenting the temperature and pressure conditions, as well as the possibility of using a catalyst that promotes the creation of ammonia. You must choose and use a similar reaction to illustrate the effect of these factors.

The file must include:

- a summary research document on the Haber process where the chemical equation is stated correctly
- an experimental procedure and a laboratory report
- an explanation of the Haber process
- the presentation of a similar reversible reaction in which the influence of at least two of the following factors are illustrated: temperature, pressure, catalyst, concentration of products or reactants

## END-OF-COURSE OUTCOMES

Learning situations are administered on the premise that the adult learner will become familiar with an investigative process involving the experimental method, the observation method or modelling. In chemistry, these learning situations foster the implementation of problem-solving skills, the use of knowledge and the production of messages.

Adult learners solving a problem related to the kinetics or state of equilibrium of a chemical system form a representation of the problem based on their reading and interpretation of scientific and technological messages. They develop a plan of action for one of their hypotheses, thus using their knowledge of reaction rates and the equilibrium constants, notably the factors that influence reaction rates and the state of equilibrium, Le Châtelier's principle and the relationship between the pH and molar concentration of hydronium and hydroxide ions. To do so, adult learners must write up an experiment protocol in which they select the required material, set down instructions with respect to the activities and determine the applicable safety rules. They implement a plan of action by carrying

out their planned laboratory activities. During these activities, they handle the materials and equipment properly, apply the appropriate safety rules and take measurements, taking into account the uncertainty associated with the instruments used and the experimental conditions. In a laboratory report, they present a rigorous analysis of the results and discuss them. Lastly, they write up the conclusions of the experiment, making connections with the initial problem. Their report mentions the sources of errors and their estimated values.

Adult learners who study a phenomenon or technological application involving chemical kinetics or chemical equilibrium formulate questions on the contextual aspects and point out the principles of chemistry involved. Using concepts, laws, theories or models, they explain the relationship between the pH and the molar concentration of hydronium and hydroxide ions, or how the modification of certain factors influences the reaction rate or the state of equilibrium. In this way, they illustrate the influence of certain factors on the kinetics of chemical reactions or on the state of equilibrium of a chemical system, graphically determine the reaction rate, or calculate the equilibrium constant, the molar concentration of substances or the pH of a solution. Lastly, adult learners demonstrate their understanding of the principles of chemistry by describing the effect of the variation of certain initial parameters and by applying their explanations to other phenomena or applications governed by the same principles.

## EVALUATION CRITERIA FOR THE COMPETENCIES TARGETED BY THE COURSE

| Evaluation Criteria for Competency 1 | Evaluation Criteria for Competency 2 | Evaluation Criteria for Competency 3 |
|---|---|---|
| ▪ Appropriate representation of the situation<br>▪ Development of a suitable plan of action<br>▪ Appropriate implementation of the plan of action<br>▪ Development of relevant explanations, solutions or conclusions | ▪ Formulation of appropriate questions<br>▪ Appropriate use of knowledge in chemistry<br>▪ Suitable production of explanations | ▪ Accurate interpretation of scientific or technological messages<br>▪ Appropriate production or transmission of scientific or technological messages |