# Past, present and future of General Chemistry in the PUC-Rio.

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## Abstract

*This manuscript describes the role of chemistry as a vehicle of understanding many other basic sciences and engineering based on the experience acquired on the General Chemistry course at the "Center Technical - Scientific" in the Pontific Catholic University of Rio de Janeiro (CTC-PUC-Rio).*

*A description of the history of the General Chemistry course is presented, including the discussion of emends, course structure, learning systems, text books, teachers' formation and their role. It is also described the actual activities of General Chemistry, such as integration of chemistry with environment. The laboratory course, the structure of involved group and the role each one, the mainly difficulties as emend amplitude and the school routine are also analyzed.*

*Due to the difficulty in choosing an adequate text book, a structure of a note book is presented, which contains the emend and its relation with many fields of science, enriched with exercises and examples.*

*A new proposal to solve many existing problems are presented, such as creation of Special Topics in General Chemistry, after the regular one, and the utilization of softwares involving important contents to a modern engineer formation.*

## Introduction

The world of chemistry is indeed a world of changes. One of the most exciting aspects of chemistry is that it is still quite realistic to expert that individual scientists working in their laboratories can discover and characterize new substances having novel properties leading to practical applications.

Chemistry plays a vital role in such areas as electronic and optical devices for advanced computers and communication systems, biotechnology, and high-performance materials. Chemistry will also be a central scientific discipline in the efforts to understand global climate changes, develop affordable energy resources, and combat AIDS and other epidemic diseases. Indeed, scientists with a strong background in chemistry have became leaders in molecular biology, advanced materials, medicine and environmental science.

In all universities of role world, the General Chemistry discipline is offered in the first periods of basic sciences (as biology, physics and geology) and engineering (as metallurgy, civil, mechanical and electrical) beyond the Chemistry courses (as engineering, industrial and bachelor chemistry). The purpose of this course is to introduce the basic facts and principles of chemistry to the student.

The basic content of this discipline is: matter and measurements, atomic theory, chemical compounds, chemical reactions, aqueous solution reactions, gases, thermochemistry, quantum theory principles, periodic table, chemical bonding, liquids-solids and intermolecular forces, solutions, chemical kinetics, chemical equilibrium, acids and bases, solubility and complex equilibrium, thermodynamics, electrochemistry, nuclear chemistry, organic chemistry and biochemistry. According to the graduate course, this basic emend can be modified. Among recent published books, one can observe that there are different approaches for the same subject; for example like those where central concepts are directed to fields of organic chemistry and biochemistry. There is no more rigid frontiers between basic sciences in function of the evolution of knowledge and technology development.

This manuscript is concerned to the history, experiences, and to a new proposal for the General Chemistry course dedicated to Basic Sciences and Engineering at Pontific Catholic University of Rio de Janeiro, Brazil.

## Past

Since 1952 it has been offered the discipline of General Chemistry for students of chemistry, civil, mechanical and electrical engineering. More recently, in the 70's decade it has been offered to the regular courses of chemistry,

physics, mathematics and other new engineering course of the "Technical – Scientific Center" at Pontific Catholic University of Rio de Janeiro (CTC-PUC-Rio).

The model initially used was similar to the German Universities where the theoretical classes were accompanied by laboratory demonstrations or by the exhibition of several scientific films. In 1976 began the activities of the General Chemistry Laboratory with experiences extracted from the book of Cotton, Lynch and Macedo [1] which was translated to Portuguese. It was then created a note book with seventeen experiments which are showed in table 1. At the 90's, it was introduced novel few experiences about environment, that included "Water Quality Tests" and "Water Purification".

A lot of money was expended by the Chemistry Department to organize the new lab which still site in the rooms 170 and 172 of Pe. Leopoldo Hainberger S.J. building. At this time and during the 80s, *Understanding Chemistry* by George C. Pimentel and Richard D. Spratley, edited by Holden-Day Inc. in 1971 was used as text book. This book [2] was translated for Portuguese by Ernesto Giesbrecht et al from Institute of Chemistry of the University of São Paulo (Brazil) and edited by publishing house Edgard Blücher Ltda. Due to the insufficient time for the course to be done, only the first part of Vol. 1 was used. It has a good approach of Science and Chemistry, Energy of Ionization and Periodical Table. It has also a microscopy approach of equilibrium, Heterogeneous equilibrium, Acid - Bases' dissociation equilibrium, Spontaneous processes and Electrochemistry. In 1984 the book was changed to *Chemical Principles* by William L. Masterton and Emil J. Slowinski, edited by W.B. Saunders Company in 1977. This book [3] also was translated to Portuguese by Domingos C.D. Neto and Antonio F. Rodrigues from State University of Rio de Janeiro (Brazil). It was used some principal chapters as Thermochemistry, physical behavior of gases, periodical table chemical bonding, solutions, pure and contaminate water, spontaneous reactions, homogeneous chemical equilibrium in gas systems, reaction kinetics, atmosphere, precipitation reactions, acid and bases, acid-bases reactions, electrochemistry cells, redox reactions and nuclear reactions. In this new proposal it was added several chapters about applications of General Chemistry. At this time it was also used new texts from Journal of Chemical Education of the American Chemical Society, to modernize the contents of the old books used till then. Since that time several books in English were analyzed [4-6] to be adopted with the exigency to be translated to Portuguese. Until today quite no American books were translated to Portuguese.

At the ending of 80's, a new proposal of General Chemistry course was presented, based on the potentiality of researchers-teachers over their academic formation. It was called a "block course", where the initial block, containing theoretical aspects of atomic structure, bonding, periodic table, was developed by a inorganic researcher as teacher; the chemical equilibrium block was performed by analytical chemistry researchers, as example. It was observed an improvement on quality and quantity of the presented contents, and in the performance of the teachers. This system presented as disadvantage the difficulty of the students to absorb the teachers changes in the same period. Furthermore it is necessary a effective coordination. Although this "block course" system had been changed, it shows a great potentiality and can be used in a near future.

## Present

Recently Campos and Godoy reported in Brazilian periodical "Quimica Nova" their experience in the course of Chemistry general with the title: The environmental, a new approach for General Chemistry courses - report of an experience. This course then tested in the Department of Chemistry of PUC-Rio presented several advantages but also presented difficulties in your operationally. In this time was used one note book with the contents: introduction of ecology, nucleosynthesis of elements, atmosphere, hydrosphere, energy and lithosphere. For the support of chemistry was used one new version of Masterton/Slowinski including Stanitski of Randolph-Macon College (Ashland, Virginia) translated to the Portuguese with the title of *Princípios de Química* [7]. But, the main problem in the course of Chemistry General is the large number of students which start each year in the courses of science and technologies in PUC-Rio. About five hundred, which are generally divide in nine groups. It means there are nine groups of theory and nine of practical. As expected in a large group of teachers with different formation, a different behavior in class is observed. For example, if the teacher have formation in analytical chemistry its class is stronger in equilibrium chemistry. If is a inorganic formation, his preference is at chemical bonding. To minimize this, a strong coordination is necessary, associated to special didactical material such a specific book. Another problem is teach this course in just one semester (45 hours). To a preliminary regular chemistry are necessary at least two semesters. Recently a tentative of write a proposal containing a mix between General Chemistry and environment in form of note book (2 volumes) was developed and the program is showed in Table 2. After each chapter exist several annex with modern information observed and retired from new literature in General Chemistry and environmental chemistry [8]. Beyond that, another note book (volume 3) was also proposed containing exercises and resolution, as viewed in a example on appendix A. The large number of students led to a difficulty in elaboration and correction of tests. Usually the tests presents 5

questions, like at appendix A, which involves calculus and dissertation concerning a specific content. Simply and exclusively conceptual questions are avoided.

To carry out a course like this, it is necessary a well trained and expert group, due the large number of students and quality standard demand by PUC-Rio. This group is composed by a coordinator, lab and theoretical teachers, instructors, tutors, monitors, lab technician, and a exclusive office is necessary. The specific function of each component is presented at appendix B.

## Future

As a function of the small number of hours to a complete General Chemistry course, it will be proposed besides the regular course, many others, involving special topics of chemistry (as showed in annex of contents of table 2), such as nuclear energy, corrosion, atmosphere, polymers, water treatment and biochemistry.

All students of basic sciences and engineering, after the regular General Chemistry course, are able to frequent the new Special Topics in General Chemistry courses. In this way the students of CTC-PUC-Rio can complete and improve their formation, according to their interest in chemistry.

The new proposal for teaching General Chemistry includes one more hour for the theoretical classes and one more hour for the laboratory classes too.

In relation to the theoretical course it will be given introductory contents to disciplines such as solids, semiconductors and metal with memory to Electric Engineering, coal, corrosion, elements commercial production and water and atmospheric pollution to Civil Engineering, polymers and nuclear reactions to Mechanical Engineering. Moreover notions in organic chemistry such as notions in nylon, polyethylene and petroleum chemistry will be introduced. Some biochemical concepts in DNA, HIV and Genetic Engineering would be introduced in connection to Biochemistry.

The additional hour for laboratory classes will be used for a more detailed description of the theory involved in the experiences that will be practiced by the students. In such a way, these concepts will not be explained during theoretical classes.

Due to the great interesting of students by laboratory classes, new practices have been studied to be introduced in the course. As showed in appendix B, it is important the participation of teachers instructors and students monitors in this lab classes. It was also verified that either the application of a test or the theoretical teacher's explanation in the beginning of the class, concerning the actual practice increase the ability for its interpretation, execution and conclusion, verified on the report prepared after each lab class.

This interest by lab classes is closely related to a better comprehension of chemical concepts presented at theoretical classes.

The evolution of computers and educational softwares for Chemistry[9] has encouraged the use of these educational resources at the course of General Chemistry at our department. It was verified an increased interest for the subject with a better knowledge improvement, since the most abstract concepts could be *visualized.* Nevertheless, the very big number of students at the introductory courses has put some limitations on the use of this approach, i.e. we have worked with a very limited number of students, mainly chemistry major students. Our goal is to expand this experience to a larger number of students.

## Conclusion

After all these years of the General Chemistry course, many systems were tested, and a increasing in quality, performance, and improvement of learning and teaching models were also observed. Some of the tested models still deserve our future attention, as the "block course".

There is a need that the General Chemistry course be directed to the students to identify the connection between the many presented contents, such as showed in appendix A . This question involve different chemical equilibrium, as gas and solids solubility, weak acids and pH. Furthermore the environmental aspects such as acid rain were focused.

The difficulty of increasing the number of hours to the General Chemistry course can be solved by introduction of a new Special Topics in the second period on science basic and engineering courses. They have to approach actual and modern themes of society interest.

It is easier that the teachers involved with the first period of a General Chemistry basic course have the same academic formation.

It is also necessary the elaboration of a new book of General Chemistry in Portuguese with higher didactical quality such as American editors' books

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**Appendix A**. Example of exercise which environmental and General Chemistry concepts are present.

The natural rain is composed by water saturated with $CO_2$, from the atmosphere. For pH determination you need to solve 2 equilibrium problems. First you need determinate the $H_2CO_3$ concentration (in water), what can be do by Henry's law and below equilibrium:

$$CO_2(g) + H_2O\ (l) \Leftrightarrow H_2CO_3\ (aq)$$

The partial pressure of $CO_2$ in atmosphere is 0.00033atm.
Second equilibrium correspond to first ionization of $H_2CO_3$, which determine the pH value.

$$H_2CO_3\ (aq) \Leftrightarrow H^+\ (aq) + HCO_3^-\ (aq)$$

$$Ka_1 = [H^+].\ [HCO_3^-] / [H_2CO_3] = 4.3x\ 10^{-7}$$

a) determine the pH value of natural rain.
b) Explain the effect of acid rain, over marble (basically $CaCO_3$).

Resolution

a) $[H_2CO_3] = 3.5 \times 10^{-2}$ moles/l.atm X 0.00033 atm= $1.2 \times 10^{-5}$M

$Ka = x^2 / (1.2 \times 10^{-5} - x) = 4.3 \times 10^{-7}$ .. neglecting x in the denominator ...

$X = (5.16 \times 10^{-12})^{-} = 2.27 \times 10^{-6} = [H^+]$

So $pH = -\log (2.27 \times 10^{-6}) = 5.6$

b) Acid rain is a term which referees to the natural rain containing nitrogen and sulfur oxides dissolved and present a lower pH value. This acidity results from human activity as burning of sulfide ores in the production of metal, such as zinc and copper.
The acid rain can be harmful to some plants, fishes (caused by pH change in lakes water) and to marble monuments. Marble is mainly composed by calcium carbonate ($CaCO_3$) which dissolve in low pH water:

$$H^+\ (aq) + CaCO_3\ (s) \rightarrow Ca^{+2}\ (aq) + HCO_3^-\ (aq)$$

**Appendix B.** The specific function of the participating members of the course of General Chemistry.

Tutors:
- Accompany the performance of the student in the understanding discipline contains.
- Incentive the student in the comprehension of specific concept and developed new forms of apprenticeship.
- Analyze the results of test questions, observing the difficulty and facility of students in resolving problems.
- Participation in the application of test unique to the several classes.

Instructors:
- Teach the class lab.
- Correct test, exercises and other tasks of theoretical class
- Proposal news practical of laboratory.
- Participate at the application of test unique to the several class.

Monitors:
- Accompany the Teacher and the Instructor in the laboratory classes.
- Correct the reporting and lab tests in the laboratory classes.
- Accompany the Teacher in the organization of final degree of student in the laboratory.
- Participate at the application of test unique to the several class.

Teachers of laboratory:

- Teach the laboratory class.
- In the initial minutes of laboratory class make a theoretical introduction and explanation of experience.
- Elaboration and application of lab test.
- Proposal of news practices and improvement of the existing.
- Stimulate the integration between Tutors, Instructors and Monitors.

Teacher theoretical:
- Teach the theoretical class.
- Elaboration and application of theoretical tests and other tasks of theoretical classes.
- Participate of periodical meeting of the Teachers to evaluate academically the classes.
- Stimulate the integration between Tutors and Instructors.

Lab technician:
- Preparation of material of experience and attendance during the lab class.
- Attendance when news practical are proposals.

Office:
- Realization of the general services.

**Table 1.** Relation of the experiments selected of the study notes of chemistry laboratory.

Experiment 1.Study of combustion.

Experiment 2.Thermal behaviour of one pure and impure substance.

Experiment 3. Mass of equal volume of different gases.

Experiment 4.Study of reactions.

Experiment 5.Quantitative investigation of reaction between one metal with hydrochloric acid.

Experiment 6. Determination of the equivalent point of one precipitation reaction.

Experiment 7. kinetic study of reactions.

Experiment 8. Chemical equilibrium.

Experiment 9. Hydrogen ion concentration determination by middle indicator.

Experiment 10. Titration of neutralization.

Experiment 11. Introduction of ox-reduction.

Experiment 12. Corrosion of iron.

Experiment 13. Cells galvanic.

Experiment 14. Electrolyze of aqueous potassium iodide.

Experiment 15. Titration potentiometric.

Experiment 16. Heats of reaction.

Experiment 17. Determination of quantify of oxygen in the air.

**Table 2**. Program of new course of chemistry general.

Volume 1-

1.
The ecology and the chemistry
Levels of organization in the nature.
Ecology and the study of ecosystem.
The structure of ecosystem.
Classification of ecosystem.
Components abiotic of the ecosystem.
Component vivo of the ecosystem.
Function of ecosystem.
The molecular bases of production and consume.
Populations and communities.
The stability of ecosystems.
Environmental problem.
Glossary.
Annex 1.Carbon dioxide.
Annex 2. Nitrogen(a Component of Air)
Annex 3. Revision of matter and forms of measure.

2.
Reactions nuclear.
Radioactivity.
Rate of decay radioactive.
Annex 1. Energy in nuclear reactions.
Annex 2. Positron emission tomography.
Annex 3. The Chernobyl nuclear accident.
Annex 4. Age of the earth.
Annex 5. Radioactive contamination by plutonium production.
Annex 6. Radon.
Annex 6. Radioactivity: air pollution from radon gas.
Annex 7. Applications of radioactivity.

3.
Nucleosynthesis of elements.
Other exercises.
Annex 1. Big bang.
Annex 2. Stellar nucleosynthesis.
Annex 3. The origin of the chemical elements I.
Annex 4. The origin of the chemical elements II.
Annex 5. Stellar nucleosynthesis: a vehicle for the teaching of nuclear chemistry.
Annex 6. Origins; the chemical elements and the earth.

4.
Gases
Measurements of gases.
Law of ideal gases.
Volume of gases in reactions.
Mixing gases: law of Dalton.
Kinetic of gases.
Other exercises.
Annex 1. Ozone: an absorber of ultraviolet radiation in the stratosphere.
Annex 2. Acid rain.
Annex 3. The Greenhouse effect.
Annex 4. Science, mathematics and gases.
Annex 5. Imperfection of gases.

5.
Atmosphere.
Structure and composition of the atmosphere.
Photochemistry atmospheric.
Clime and atmospheric conditions.
Thermal inversion.
Human action and atmospheric pollution.
Global effect.
Formation and destruction of ozone.
Local effects.
Nitrogen oxides.
Annex 1. The atmosphere.
Annex 2. Air pollution and oxides of nitrogen.
Annex 3. Environmental is worst after Rio 92.

6.
Equilibrium Chemistry.
State of equilibrium.
Equilibrium: one dynamical process.
The system $N_2O_4$ –$NO_2$ in equilibrium.
General expression of $K_c$.
Reaction of liquid or solid with gases.
Application of $K_c$.
Effects of change in conditions.
$K_c$ versus $K_p$
Relation between $\Delta G$ and the equilibrium Constant.
Heterogeneous equilibrium.
Equilibrium solid-vapor.
Equilibrium liquid-vapor.
Molecular solutions.
Annex 1. The synthesis of ammonia and other nitrogen compounds.

7.
Kinetic of reactions.
The significant of rate in reactions.
Rate in reactions and concentrations.
Reactant concentration and time.
Activation energy.
Catalyze.
Rate in reactions and temperature.
Mechanism of reactions.
Other exercises.
Annex 1. Iodine: the clock reaction and the oxidation states of iodine.
Annex 2. Enzymes: nature's catalysts.
Annex 3. Sulfuric acid.
Annex 4. Summarizing example.

Volume 2-

8.
Chemistry bonding.
Ionic bonding.
Nature of covalent bonding.
Lewis structure.
Proprieties of covalent bonding.
Other exercises.
Structure molecular.
Geometry molecular.
Polarity of molecules.
Orbital atomic.
Octets expansion.
Orbital molecular.
Annex 1. Law of coulomb.
Annex 2. Phosphorus: a group VA nonmetal.
Annex 3.Polymers.
Annex 4.Infrared spectroscopy and vibrations of chemical bonds.
Annex 5. Spectroscopy.

09.
Intermolecular forces.
Tendency in the points of the fusion and ebullition.
Dipole forces.
Hydrogen bonds.
Dispersion forces.
Other exercises.
Annex 1. Water: a special substance for planet earth.
Annex 2. Natural waters.

10.
Solutions.
Terminology of solutions.
Units of concentration.
Other exercises.
Principles of solubility.
Colligatives proprieties of solutions.
Annex 1. Lead in the Environment.
Annex 2. Thermal pollution.
Annex 3. Henry's law.
Annex 4. Raoult's law.
Annex 5. Practical applications of osmosis.
Annex 6. Reverse osmosis.
Annex 7. Examples of osmotic pressure.
Annex 8. Zone refining.
Annex 9. Hemoglobin solubility and sickle-cell anemia.
Annex 10. Colloids.

11.
Reactions of precipitation.
Solubility of ionic solids.
Equilibrium of solubility.
Other exercises.
Annex 1. Complex ions and solubility.

12.
Which is one acid?
Where gone the acid?
Auto-ionization of water.
Acid and bases of Arrhenius.
Acid and base of Bronsted and Lowry.
Equilibrium expression.
Reaction between acid and bases strong.
Acidity in a solution of strong acid.
Acidity in a solution of strong base.
Variation of acidity by addition of a base.
pH scale.
Titration of a strong acid with a strong base.
pH indicators.
Acid and base weak.
Dissociation of acid and base weak.
The water as a acid and base weak.
Acetic acid: the essence of vinegar.
pH of a solution of the acetic acid.
pH of a solution of the acetic acid with sodium acetate.
pH of a solution of the sodium acetate.
Titration of a acid weak with a base also weak.
Other exercises.
Annex 1. Carbonic acid.
Annex 2. Assigning equilibria to different parts of titration curves.
Annex 3. Hydrochloric acid: a strong acid.
Annex 4. Sodium hydroxide: a strong base.
Annex 5. Acetic acid : a weak acid.
Annex 6. Ammonia: a weak base.
Annex 7. Summarizing example.

13.
Pure and contaminate water.
Fonts of natural water.
Pollution of water.
Fonts of pollution.
Species of pollutants.
Detergents.
Insecticides.
Oligo-elements.
Heat.
Purification of water.
Remove of matter in the suspension.
Sedimentation.
Flocculation.
Filtration.
Disinfecting.
Remove of smell and flavor.
Hardness of water.
Process cal-soda.
Cationic exchange.
Ionic exchange.
Other exercises.
Annex 1. Eutrophication.

14.
Thermochemistry.
Endothermic and exothermic reactions.
Thermochemical equations.
Heat of formation.
Heat flow measurement.
Thermodynamics first law.
Other exercises.
Annex 1. Summarizing example.
Annex 2. Sources and uses of energy.
Annex 3. Fuels-foods, commercial fuels, and rocket fuels.
Annex 4. Energy utilization.
Annex 5. Energy sources.

15.
Spontaneous reactions.
Enthalpy changes.
Entropy changes.
Free energy.
Thermodynamics second law.
Relation between $\Delta G$ and equilibrium constant.
Vant't Hoff equation.
Relation between $\Delta E$, $\Delta G$ and equilibrium constant.
Annex 1. Summarizing example.
Annex 2. Iron ( a transition metal).

16.
Electrochemistry
Spontaneous reactions in electrochemistry cells.
Copper concentrations cells.
Silver concentrations cells.
Standard hydrogen electrode.
Redox cells.
Semi-cells standard potential.
Relation of potential with concentration.
Equilibrium constants and potential of cells.
Cells based on precipitation.
Annex 1. Some commercial voltaic cells.
Annex 2 . Summarizing examples.
Annex 3. Hydrogen economy.
Annex 4. Hydrogen: fuel of the twenty-first century?
Annex 5. The Chlor-Alkali process.

17.
Organic chemistry and biochemistry
Functional groups in organic molecules.
Organochlorine compounds.
Alcohols.
Carboxylic acids.
Esters.
Amines.
Isomerism in organic compounds.
Synthetic polymers.
Addition polymers.
Condensation polymers.
Natural polymers.
Annex 1. Biochemistry.