

RADIATION CHEMISTRY

FROM BASICS TO
APPLICATIONS IN MATERIAL
AND LIFE SCIENCES

EDITED BY :

Mélanie SPOTHEIM-MAURIZOT,
Mehran MOSTAFAVI,
Thierry DOUKI,
Jacqueline BELLONI



COLLECTION DIRECTED BY **Paul RIGNY**

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17 avenue du Hoggar
Parc d'activité de Courtaboeuf, BP 112
91944 Les Ulis Cedex A, France

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Foreword

“L’Actualité Chimique” is a monthly scientific journal meant to convey information on progress in the chemical sciences to a public endowed with a certain ability to master scientific matters. The articles were written by scientists who took time out of their laboratories to explain their studies and their knowledge with a pedagogy and an appeal suitable for non-specialists. Mostly written in French, it creates a bond in the chemical community in French-speaking countries where it is very much appreciated by scientists, teachers and engineers.

However, the scope of the journal implies some limits that we want to erase with this new collection “L’Actualité Chimique – Livres”, which will be complementary in two directions: the first one is illustrated by the present book, as it addresses readers more specialized than the journal usually does, and being written in English, it has the ambition of attracting attention worldwide on a field of chemistry where recent progress is noted. The second direction that will be found in the new collection is, in contrast, that of disseminating the progress of chemistry for the benefit of a large, French-speaking, not necessarily professional public. The first trend will produce books that we will find in many laboratories; books produced according to the second trend will instead be largely found in public libraries, in schools or even in the homes of scientifically curious people.

This first volume of “L’Actualité Chimique – Livres” is of the first kind and devotes itself to **Radiation Chemistry – From basic science to applications in biology and material science.**

This field of research is undergoing a true and fruitful rejuvenation. Already active in the mid - 20th century, the development of this scientific field had been somewhat slowed down by the high cost of short-pulse particle accelerators and specialized construction. Recent progress in instrumentation *e.g.* : the shaping of picosecond radiation pulses, faster time-resolved detection techniques, and powerful molecular structure determination techniques, has coincided to enhance the capacity of radiation chemistry sufficiently to warrant new investments and the start of new laboratories. Radiation chemistry today is responsible for major progress in the understanding of the elementary chemical event and powerful enough to unravel the mechanisms of the damage induced by radiation to living matter (a question of great concern in the public) or the transformations induced in irradiated materials.

These aspects are developed in the book by international-level specialists and will be of interest to scientists who are starting in the field, to more experienced ones, and also to students and teachers; it will also be very useful to many professionals who apply or deal with radiation in their activities to improve materials or to avoid radiation-induced damage to them.

Paul RIGNY
Chief Editor of "L'Actualité Chimique"
March 2008

Preface

Radiation chemistry deals with the chemical reactions resulting from the interaction of high-energy photons or particles with matter. Such radiation possesses energy high enough to induce ionisation of the components of the material and the breaking and building of chemical bonds.

In the present volume, our purpose is to familiarise the larger communities of students and chemists in other specialities with this relatively little-known but essential domain of chemistry. The covered topics range from the basics (primary phenomena and mechanisms) to the broad fields of their application. Understanding radiation-induced chemical and biochemical reactions is essential for improving existing processes and developing new ones.

Therefore we have called upon internationally recognized experts who kindly agreed to contribute to this volume with clear, instructive and pedagogically presented chapters abundantly illustrated with attractive colour figures.

The first chapters of Part I deal with primary radiolytic phenomena and describe recent developments at the facilities used to create radiation-induced species, as well as the most advanced methods for their detection and study. The mechanisms of radiation-matter interactions and their consequences for the physical chemistry of liquids and solutions are discussed.

Part II describes specific mechanisms and key processes in space and nuclear chemistry, as well as in material sciences and pharmaceutical and food chemistry. The high energy of ionizing radiation offers the specific advantage of easy and homogeneous sample penetration. Therefore, by targeting chemical bonds at room temperature via cost-competitive, chemical additive-free processes, ionizing radiation can be used for many interesting purposes. For example, thanks to the understanding of radiation-induced nucleation/growth processes, the final size and properties of metal nanoclusters can be controlled for applications in catalysis, electronics, and photography. High-performance polymeric materials, obtained using the cleavage or the formation of chemical bonds by irradiation, have a multitude of uses in everyday life. Remediation of waste-water requires the destruction of toxic chemicals, which is efficiently accomplished by irradiation. The use of ionizing radiation for food treatment and the sterilization of pharmaceuticals and medical devices operate *via* the efficient destruction of micro-organisms, but they require systematic confirmation of the absence of any toxic molecules that could be produced during irradiation.

The search for new means of improving the success of cancer radiotherapy motivates an increasing interest in the chemical mechanisms underlying radiobiology. Part III of the volume is devoted to this very active research domain, and in particular, to studies of the damage induced by ionizing radiation in biomolecules (DNA, proteins, lipids). Answers are given as to what are the mechanisms of the reactions in DNA and other biomolecules following the initial ionization and excitation, how they can be simulated by computational models, how radiation-induced lesions are repaired or prevented, and finally how this improved knowledge is used to specifically eradicate tumours (cancer radiotherapy).

With no pretence of exhaustively covering in detail all the topics of radiation chemistry, this volume will hopefully fulfil the expectation of the reader to learn about a domain that we consider a most exciting and promising area of chemistry.

We cannot end this preface without addressing our thanks to Yann Gauduel and Paul Rigny, respectively former and present Chief Editors of “ L’Actualité Chimique”, who solicited and accompanied us in the realisation of this work. All the other members of the editorial board of the journal and of EDP Sciences are equally warmly thanked.

Mélanie SPOTHEIM-MAURIZOT,
Mehran MOSTAFAVI,
Thierry DOUKI,
Jacqueline BELLONI
March 2008

List of Authors

AMOURETTE Christine

Service de Santé des Armées / Centre de Recherches

24, Av. des Maquis du Grésivaudan - 38702 La Tronche / FRANCE

camourette@crssa.net

BALDACCHINO Gérard

Commissariat à l'Énergie Atomique / Laboratoire de Radiolyse

Bât. 546 CEA/Saclay - 91191 Gif-sur-Yvette / FRANCE

gerard.baldacchino@cea.fr

BALOSSO Jacques

CHU A. Michallon / Service de Cancérologie-Radiothérapie

BP 217 - 38043 Grenoble cedex 9 / FRANCE

jbalosso@chu-grenoble.fr

BELLONI Jacqueline

CNRS-Université Paris-Sud / Laboratoire de Chimie Physique-ELYSE

Bât. 349 Université Paris-Sud - 91405 Orsay / FRANCE

jacqueline.belloni@lcp.u-psud.fr

BERLIN Yuri

Northwestern University / Department of Chemistry

2145 Sheridan Road - Evanston, IL 60208-3113 / USA

berlin@chem.northwestern.edu

BERNHARD William

University of Rochester / Department of Biochemistry and Biophysics

575 Elmwood avenue, Box 712

Rochester, NY 14642 / USA

william_bernhard@urmc.rochester.edu

BOBROWSKI Krzysztof

Institute of Nuclear Chemistry and Technology

Dept of Radiation Chemistry and Technology

Dorodna 16, 03-195 Warsaw / POLAND

kris@ichtj.waw.pl

BOUNIOL Pascal

Commissariat à l'Énergie Atomique Saclay / Laboratoire des Bétons

Bât. 158 - 91191 Gif-sur-Yvette / FRANCE

pascal.bouniol@cea.fr

BUXTON Georges

1A Hollin Crescent - Leeds LS16 5ND / UNITED KINGDOM

george.buxton@talktalk.net

CADET Jean

CEA Grenoble / DRFMC/SCIB

17 rue des Martyrs - 38054 Grenoble cedex 9 / FRANCE

jcadet@cea.fr

CASTAING Bertrand

CNRS / Centre de Biophysique Moléculaire

Rue Charles Sadron - 45071 Orléans cedex 2 / FRANCE

castaing@cnrs-orleans.fr

COQUERET Xavier

Université de Reims Champagne-Ardenne / Réactions Sélectives et Applications

Europol'Agro - 51687 Reims cedex 2 / FRANCE

xavier.coqueret@univ-reims.fr

DAVIDKOVA Maria

Nuclear Physics Institute / Dept of Radiation Dosimetry

Na Truhlarce 39/64 - 18086 Praha 8 / CZECH REPUBLIC

davidkova@ujf.cas.cz

DAWES Anita

The Open University / Department of Physics and Astronomy

Walton Hall - Milton Keynes MK7 6AA / UNITED KINGDOM

a.dawes@open.ac.uk

DOUKI Thierry

CEA Grenoble / DRFCM/SCIB

17 rue des Martyrs - 38054 Grenoble cedex 9 / FRANCE

tdouki@cea.fr

EMMI Salvatore Silvano

CNR / ISOF

Via P. Gobetti, 101 - 40129 Bologna / ITALY

emmi@isof.cnr.it

FORAY Nicolas

INSERM / European Synchrotron Radiation Facility

BP 220-38043 Grenoble cedex / FRANCE

foray@esrf.fr

GARDES-ALBERT Monique

Université René Descartes Paris V / Laboratoire de Chimie Physique

45 Rue des Saints-Pères - 75270 Paris cedex 06 / FRANCE

Monique.Gardes@univ-paris5.fr

HICKEL Bernard

Commissariat à l'Énergie Atomique / Laboratoire de Radiolyse

Bât. 546 CEA/Saclay - 91191 Gif-sur-Yvette / FRANCE

b.hickel@wanadoo.fr

HOLTOM Philip

The Open University / Department of Physics and Astronomy

Walton Hall - Milton Keynes MK7 6AA / UNITED KINGDOM

p.holtom@open.ac.uk

HOUEE-LEVIN Chantal

Université Paris-Sud / Laboratoire de Chimie Physique

bât. 350 - 91405 Orsay / FRANCE

chantal.houee-levin@lcp.u-psud.fr

KISTER Jacky

Université Paul Cezanne Aix-Marseille / Systèmes chimiques complexes

CNRS-UMR Faculté de St-Jérôme 6171

13397 Marseille cedex 20 / FRANCE

Jacky.kister@univ-cezanne.fr

LAMPRE Isabelle

Université Paris-Sud / Laboratoire de Chimie Physique

Bât. 349 - 91405 Orsay / FRANCE

isabelle.lampre@lcp.u-psud.fr

MASON Nigel J

The Open University / Department of Physics and Astronomy
Walton Hall - Milton Keynes MK7 6AA / UNITED KINGDOM

n.j.mason@open.ac.uk

MOSTAFAVI Mehran

Physical Chemistry Institute, Centre ELYSE-CLIO
CNRS / University Paris-Sud, Orsay / FRANCE

mehran.mostafavi@lcp.u-psud.fr

PROUILLAC Caroline

Université Paul Sabatier / Laboratoire Hétérochimie Fondamentale et Appliquée
118 Route de Narbonne - 31062 Toulouse / FRANCE

prouilla@chimie.ups--tlse.fr

RAFFI Jacques

CEA Université Paul Cezanne Aix-Marseille III
Laboratoire de Radiolyse de la Matière organique
Avenue Escadrille Normandie-Niémen
13397 Marseille cedex 20 / FRANCE

j.raffi@univ.u-3mrs.fr

REMITA Hynd

Université Paris-Sud / Laboratoire de Chimie Physique
Bât. 349 - 91405 Orsay / FRANCE

hynd.remita@lcp.u-psud.fr

RIMA Ghassoub

Université Paul Sabatier / Laboratoire Hétérochimie Fondamentale et Appliquée
118 Route de Narbonne - 31062 Toulouse / FRANCE

rima@chimie.ups--tlse.fr

SAGE Evelyne

CNRS / Institut Curie
Centre Universitaire - 91405 Orsay / FRANCE

evelyne.Sage@curie.u-psud.fr

SEVILLA Michael D.

Oakland University / Department of Chemistry
Rochester - 48309 Michigan / USA

sevilla@oakland.edu

SIEBBELES Laurens

Delft University of Technology
Mekelweg 15 - Delft 2629 JB / THE NETHERLANDS

L.D.A.Siebbeles@tnw.tudelft.nl

SPOTHEIM-MAURIZOT Mélanie

INSERM senior scientist, Molecular Biophysics

Centre – CNRS, Orléans / FRANCE

spotheim@cnrs-orleans.fr

TAKACS Erzsebet

Hungarian Academy of Sciences / Institute of isotopes and surface chemistry

PO Box 77 - 1525 Budapest / HUNGARY

takacs@iki.kfki.hu

TILQUIN Bernard

Université Catholique Louvain 72-30

Unité d'Analyse Chimique et Physico-Chimique des Médicaments

72 Avenue E. Mounier - B1200 Bruxelles / BELGIQUE

tilquin@cham.ucl.ac.be

WISHART James

Brookhaven National Laboratory / Chemistry Department

Upton, NY 11973 / USA

wishart@bnl.gov

Part I

Primary radiation-induced phenomena

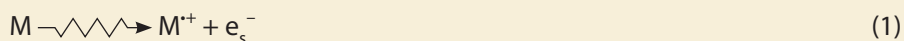
Chapter 1

An overview of the radiation chemistry of liquids

George V. BUXTON

Introduction

Radiation chemistry is the chemistry initiated by the interaction of high-energy photons and atomic particles with matter, so-called ionising radiation. As a method of generating free radicals for applications in general chemistry the most commonly used sources of ionising radiation are ^{60}Co γ -rays, which are photons having energies of 1.17 and 1.33 MeV ($1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$), or fast electrons from an accelerator with energies typically in the range 2-20 MeV. The dose absorbed by the material is expressed in grays ($1 \text{ Gy} = 1 \text{ J kg}^{-1}$) and the dose rate in Gy s^{-1} . In each case the result of the interaction of high energy particles with molecules is the ejection of a single electron, called a secondary electron which itself may have sufficient energy to cause further ionisations, but which rapidly ($< 10^{-12} \text{ s}$) reaches thermal equilibrium with the liquid and becomes trapped as a so-called solvated electron (e_s^-). In this way, stable molecules (M) are converted into solvated electrons and highly reactive free radicals (M^+):



Pulse radiolysis experiments have provided clear evidence for solvated electrons in both polar (water, alcohols, etc.) and non-polar (alkanes) liquids through their optical absorption spectra.

An important characteristic of ionising radiation is that it is absorbed non-selectively so that molecules are ionised according to their relative abundance in the medium of interest.

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