Karl Heinrich Lieser

Nuclear and Radiochemistry

Fundamentals and Applications

Second, Revised Edition

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Preface

This textbook gives a complete and concise description of the up-to-date knowledge of nuclear and radiochemistry and applications in the various fields of science. It is based on teaching courses and on research spanning over 40 years.

The book is mainly addressed to chemists desiring sound information about this branch of chemistry dealing with the properties of radioactive matter. Students and scientists working in other branches of chemistry, in enviromental science, physics, geology, mineralogy, biology, medicine, technology and other fields will also find valuable information about the principles and applications of nuclear and radiochemistry.

Nuclear science comprises three overlapping fields, nuclear physics, nuclear and radiochemistry, and nuclear technology. Whereas nuclear physics deals with the physical properties of the atomic nucleus and the energetic aspects of nuclear reactions, in nuclear and radiochemistry the chemical aspects of atomic nuclei and of nuclear reactions (nuclear chemistry) and the chemical properties, preparation and handling of radioactive substances (radiochemistry) are considered. The concern of nuclear technology, on the other hand, is the use of nuclear energy, in particular the production of nuclear fuel and the operation of nuclear reactors and reprocessing plants. A well-founded knowledge of nuclear reactions and of nuclear and radiochemistry is needed in nuclear technology. Another related field, radiation chemistry, deals with the chemical effects of radiation, in particular nuclear radiation, and is more closely related to physical chemistry.

Research in nuclear and radiochemistry comprises: Study of radioactive matter in nature, investigation of radioactive transmutations and of nuclear reactions by chemical methods, hot atom chemistry (chemical effects of nuclear reactions) and influence of chemical bonding on nuclear properties, production of radionuclides and labelled compounds, and the chemistry of radioelements – which represent more than a quarter of all chemical elements.

Applications include the use of radionuclides in geo- and cosmochemistry, dating by nuclear methods, radioanalysis, the use of radiotracers in chemical research, Mössbauer spectrometry and related methods, the use of radionuclides in the life sciences, in particular in medicine, technical and industrial applications and investigations of the behaviour of natural and man-made radionuclides, in particular actinides and fission products, in the environment (geosphere and biosphere). Dosimetry and radiation protection are considered in the last chapter of the book.

Fundamentals and principles are presented first, before progressing into more complex aspects and into the various fields of application. With regard to the fact that radioactivity is a property of matter, chemical and phenomenological points of view are presented first, before more theoretical aspects are discussed. Physical properties of the atomic nucleus are considered insofar as they are important for nuclear and radiochemists.

Endeavours are made to present the subjects in clear and comprehensible form and to arrange them in a logical sequence. All the technical terms used are defined when they are first introduced, and applied consistently. A glossary can be found at the end of the text. In order to restrict the volume of the book, detailed derivations of equations are avoided and relevant information is compiled in tables, as far as possible. More complex relations are preferably elucidated by examples rather than by giving lengthy explanations.

For further reading, relevant literature is listed abundantly at the end of each chapter. Generally, it is arranged in chronological order, beginning with literature of historical relevance and subdivided according the subject matter, into general and more special aspects.

I am indebted to many colleagues for valuable suggestions, and I wish to thank Mrs. Boatman for reading the manuscript.

Darmstadt, April 1996 K. H. Lieser

Preface to the second edition

After concept and structure of the book proved to be useful, they have not been changed in the second edition. However, new developments and results have been considered and the text has been revised taking into account new data.

In preparing this edition, I enjoyed the assistance of my son Joachim Lieser, who gave me many valuable hints.

I acknowledge the readiness of the publishers to supplement the text and to make the corrections necessary to bring this book up to date.

Darmstadt, April 2000 K. H. Lieser

Contents

1 Radioactivity in Nature

1.1 Discovery of Radioactivity

Radioactivity was discovered in 1896 in Paris by Henri Becquerel, who investigated the radiation emitted by uranium minerals. He found that photographic plates were blackened in the absence of light, if they were in contact with the minerals. Two years later (1898) similar properties were discovered for thorium by Marie Curie in France and by G. C. Schmidt in Germany. That radioactivity had not been discovered earlier is due to fact that human beings, like animals, do not have sense organs for radioactive radiation. Marie Curie found differences in the radioactivity of uranium and uranium minerals and concluded that the minerals must contain still other radioactive elements. Together with her husband, Pierre Curie, she discovered polonium in 1898, and radium later in the same year.

Radioactivity is a property of matter and for the detection of radioactive substances detectors are needed, e.g. Geiger–Müller counters or photographic emulsions. It was found that these detectors also indicate the presence of radiation in the absence of radioactive substances. If they are shielded by thick walls of lead or other materials, the counting rate decreases appreciably. On the other hand, if the detectors are brought up to greater heights in the atmosphere, the counting rate increases to values that are higher by a factor of about 12 at a height of 9000 m above ground. This proves the presence of another kind of radiation that enters the atmosphere from outside. It is called cosmic radiation to distinguish it from the terrestrial radiation that is due to the radioactive matter on the earth. By cascades of interactions with the gas molecules in the atmosphere, cosmic radiation produces a variety of elementary particles (protons, neutrons, photons, electrons, positrons, mesons) and of radioactive atoms.

1.2 Radioactive Substances in Nature

Radioactive substances are widely distributed on the earth. Some are found in the atmosphere, but the major part is present in the lithosphere. The most important ones are the ores of uranium and thorium, and potassium salts, including the radioactive decay products of uranium and thorium. Uranium and thorium are common elements in nature. Their concentrations in granite are about 4 and 13 mg/kg, respectively, and the concentration of uranium in seawater is about 3 µg/l. Some uranium and thorium minerals are listed in Table 1.1. The most important uranium mineral is pitchblende (U_3O_8). Uranium is also found in mica. The most important thorium mineral is monazite, which contains between about 0.1 and 15% Th.

The measurement of natural radioactivity is an important tool for dating, e.g. for the determination of the age of minerals (see section 16.1).