CONTENTS

Foreword 11

Chapter 1 Subatomic structure of matter *(O. Navrátil)* 13
1.1 Matter, field and interactions 13
1.2 Elementary and fundamental particles 15
1.3 Equivalence of mass and energy 19
1.4 Atomic nucleus 20
1.4.1 Nuclear forces, composition and dimension of atomic nucleus . . . 20
1.4.2 Spin, magnetic and quadrupole moments 22
1.4.3 Nuclear mass and binding energy 24
1.4.4 Nuclear stability 26
1.4.5 Nuclear models 29
Literature 33

Chapter 2 Nuclear transmutations *(V. Mikulaj)* 34
2.1 Radioactive transmutations of nuclides 34
2.1.1 Basic characteristics of radioactive transmutations 34
2.1.2 Kinetics of radioactive transmutations 37
2.1.2.1 Simple radioactive transmutation 37
2.1.2.2 Successive radioactive transmutations 40
2.1.2.3 Branched radioactive transmutations 43
2.1.3 Gamma transmutations and isomeric transitions 44
2.1.4 Beta transmutations. 46
2.1.5 Alpha transmutations 49
2.1.6 Spontaneous fission 51
2.1.7 Spontaneous emission of nucleons 52
2.1.8 Influence of the physical and chemical state of the radionuclide on the transmutation rate 53
2.2 Nuclear reactions 53
2.2.1 Basic characteristics of nuclear reactions 54

2.2.2 Effective cross-sections and kinetics of nuclear reactions 57
2.2.3 Mechanisms of nuclear reactions 61
2.2.4 Reactions of neutrons 64
2.2.5 Fission reaction 67
2.2.6 Nuclear reactions induced by charged particles and photons . . . 70
2.3 Chemical reactions caused by nuclear transmutations 73
2.3.1 Recoil energy and properties of hot atoms 73
2.3.2 Szilard-Chalmers effect 76
2.3.3 Chemical consequences of radioactive transmutations 77
2.4 Behaviour of radionuclides at trace concentrations 78
Literature 81

Chapter 3 Properties of nuclides and nucleogenesis *(R. Kopunec)* . . . 83
3.1 General characteristics of nuclides 83
3.1.1 Systematic classification of nuclides 83
3.1.2 Natural nuclides 85
3.1.3 Natural radioactivity 87
3.1.4 Nuclear chronology 92
3.2 Isotopy of elements 93
3.2.1 The concept of isotopes 93
3.2.2 Isotope effects 95
3.2.3 Methods of isotope concentration and separation 98
3.3 Radioactive elements 105
3.3.1 General characteristics 105
3.3.2 Technetium and promethium 107
3.3.3 Elements with atomic numbers 84–91 109
3.3.4 Uranium, neptunium, and plutonium 113
3.3.5 Heavier actinides (elements with atomic numbers 95–103) 115
3.3.6 Translawrencium elements 119
3.4 Nucleogenesis of chemical elements in the universe 123
3.5 Generalized state diagram of matter 125
Literature 129

Chapter 4 Effects of nuclear radiation *(F. Macášek)* 131
4.1 Propagation and absorption of radiation 131
4.1.1 Attenuation and range of nuclear radiation 132
4.1.2 Mechanism of energy loss 136
4.1.3 Excitation and ionization of molecules. Formation of radicals . . . 140
4.1.4 Radiation-physical phenomena 142
4.1.5 Exposure and absorbed radiation dose 143
4.1.6 Radiation sources. 144
4.2 Radiation-chemical reactions. 148

4.2.1 Mean yield of radiation-chemical reactions 148
4.2.2 Reactions of the primary radiolysis products 149
4.2.3 Recombination reactions of radicals 152
4.2.4 Steady-state concentrations of radicals formed by irradiation . . . 154
4.3 Radiolysis of water and aqueous solutions 158
4.3.1 Radical and molecular products of radiolysis 158
4.3.2 Reactions of the $\dot{H}$ radical and solvated electron 159
4.3.3 Reactions of radicals $\dot{O}H$, $H\dot{O}_2$, and O_2^- 161
4.3.4 Aqueous solutions as chemical dosimeters 162
4.4 Radiolysis of organic substances 163
4.4.1 Radiolysis of pure liquids 163
4.4.2 Radiolysis of solutions. 166
4.4.3 Radiolysis in gas-liquid systems. 168
4.4.4 Radiolysis of polymers 169
4.5 Biological effects of ionizing radiation. 171
4.5.1 Molecular, subcellular, and cellular levels. 171
4.5.2 Somatic and genetic effects 173
4.5.3 Radiation hygiene 174
Literature 176

Chapter 5 Analysis of nuclides *(J. Hála* and *O. Navrátil)* 177
5.1 Analysis of radioactive nuclides 177
5.2 Detection and measurement of ionizing radiation 179
5.2.1 Ion collection methods 180
5.2.1.1 Gas-filled detectors 180
5.2.1.2 Solid state detectors. 186
5.2.2 Scintillation methods 189
5.2.2.1 Scintillation detector. 189
5.2.2.2 Inorganic scintillators 191
5.2.2.3 Liquid scintillation counting 193
5.2.2.4 Čerenkov counting 196
5.3 Spectrometry of ionizing radiation 197
5.3.1 Pulse height analysis 197
5.3.2 Alpha spectrometry. 200
5.3.3 Gamma and X-ray spectrometry 201
5.3.4 Beta spectrometry 205
5.4 Errors in radioactivity measurement. 208
5.5 Radiographic methods 212
5.5.1 Photographic methods. 212
5.5.2 Solid state track detectors 214
5.6 Mass spectroscopy 215
5.6.1 Abundance mass spectroscopy 215

5.6.2 Accelerator mass spectroscopy 218
5.7 Other methods of stable nuclide analysis. 219
5.7.1 Atomic and molecular optical spectroscopy. 219
5.7.2 Gas chromatography 223
5.7.3 Nuclear magnetic resonance 224
Literature 225

Chapter 6 Production of radionuclides and labelled compounds *(L. Lešetický)* 226
6.1 Sources of nuclear projectiles 226
6.1.1 Sources of charged particles 226
6.1.2 Neutron sources 228
6.1.3 Sources of high-energy photons. 229
6.2 Activation techniques. 230
6.2.1 Neutron reactions 230
6.2.2 Reactions of charged particles 231
6.3 Production of radionuclides 232
6.3.1 Thermal neutron activation 232
6.3.2 Charged particle activation. 234
6.3.3 Radionuclide generators. 235
6.4 Nomenclature of labelled compounds 236
6.5 Preparation of labelled compounds 237
6.5.1 Isotope exchange. 237
6.5.2 Radiochemical methods 240
6.5.2.1 Recoil labelling. 240
6.5.2.2 Wilzbach method 242
6.5.3 Synthetic methods 244
6.5.3.1 Hydrogen isotopes 244
6.5.3.2 Carbon isotopes 246
6.5.3.3 Isotopes of halogens. 248
6.6 Stability of labelled compounds 250
Literature 253

Chapter 7 The method of isotopic tracers *(J. Hála)* 254
7.1 Equivalence of chemical bonds. 255
7.2 Existence of unstable compounds. 256
7.3 The course of chemical reactions 256
7.3.1 Reaction mechanisms 256
7.3.2 Molecular rearrangements 259
7.3.3 Biosynthesis 260
7.3.4 Metabolic studies. 262
7.4 Tracers in kinetic studies 264

7.5 Sequencing of nucleic acids 269
7.6 Self-diffusion 271
7.7 Surface area determination 272
7.8 Solubility of sparingly soluble substances 273
7.9 Distribution of substances between two phases 274
7.10 Emanometry 276
7.11 Tracer method in chemical analysis 277
7.11.1 Direct counting of natural radionuclides. 278
7.11.2 Radiometric titrations 278
7.11.3 Isotope dilution 279
7.11.4 Radioactive reagents 282
7.11.5 Methods based on exchange (displacement) reactions 282
7.11.6 Radiorelease methods 283
7.11.7 Radioimmunoassays (RIA) and related methods 284
7.12 Tracers in chemical industry and related areas 286
Literature 290

Chapter 8 Interaction methods of analysis *(J. Hála)* 291
8.1 Activation analysis 291
8.1.1 Qualitative and quantitative analysis. 292
8.1.2 Procedure 294
8.1.3 Neutron activation analysis (NAA) 296
8.1.4 Charged particle analysis (CPAA). 299
8.1.5 Photoactivation 300
8.1.6 Prompt activation analysis 300
8.1.7 Stable isotope analysis via activation. 302
8.2 Radionuclide X-ray fluorescence analysis (RXFA) and particle induced X-ray emission (PIXE) methods 303
8.3 Analytical methods based on absorption and scattering of nuclear radiation 307
8.3.1 Absorption of beta radiation 307
8.3.2 Absorption of gamma and X-rays 308
8.3.3 Absorption of neutrons 309
8.3.4 Alpha particle scattering. 310
8.3.5 Beta particle back-scattering 311
8.3.6 Gamma radiation scattering 312
8.3.7 Neutron scattering 313
8.4 Application of absorption and scattering methods in chemical industry 313
8.5 Resonance absorption of gamma-radiation – Mössbauer effect . . . 315
Literature 320

Chapter 9 Nuclear-chemical technology *(V. Mikulaj)*. 321

9.1 Nuclear reactors 321
9.1.1 Chain fission reaction 321
9.1.2 Controlled chain reaction. Basic characteristics and types of nuclear reactors 325
9.1.3 Thermal power reactors. Nuclear power stations 328
9.1.3.1 Light-water reactors 331
9.1.3.2 Heavy-water reactors 333
9.1.3.3 Graphite reactors. High-temperature reactors 333
9.1.4 Fast breeder reactors 335
9.2 Processing of irradiated nuclear fuel 336
9.2.1 Formation of secondary fissionable materials 336
9.2.2 Properties and processing of burnt-up nuclear fuel. 338
9.2.3 Manufacture of plutonium and uranium-233 341
9.2.4 Production of transuranium elements and other nuclides 343
9.3 Production of nuclear fuel and reactor materials 346
9.3.1 Production of uranium 346
9.3.2 Production of thorium. 348
9.3.3 Other reactor materials 349
9.4 Radioactive waste management. 350
9.5 Thermonuclear reactors. 351
Literature 353

Chapter 10 Radionuclides in the environment *(L. Lešetický)* 355
10.1 Sources of radionuclides 355
10.1.1 Natural sources 355
10.1.2 Artificial sources 356
10.1.3 Nuclear accidents 361
10.2 Transfer of radionuclides into animal organisms 364
10.2.1 Transfer pathways 364
10.2.2 Ecological significance of some radionuclides 366
Literature 369

Appendix 1. 371
Appendix 2. 372
Appendix 3. 376
Index 379