

Contents

Preface — V

Acknowledgements — VII

Part A: Diagnostics without ionizing radiation

1	Sonography — 3
1.1	Introduction and overview — 3
1.2	Ultrasound transducer — 4
1.2.1	Piezoelectric effect — 4
1.2.2	Ultrasonic head — 6
1.3	Reflection, transmission, and attenuation — 9
1.3.1	Reflection, transmission, and scattering — 9
1.3.2	Scattering and absorption — 11
1.4	Beam properties, pulsing, and focusing — 13
1.4.1	Pulse quality — 13
1.4.2	Time gain compensation — 14
1.4.3	Near field, far field, and focusing — 15
1.4.4	Physical parameters — 18
1.4.5	Safety issues — 18
1.5	Medical imaging — 19
1.5.1	A-mode scan — 19
1.5.2	B-mode scan — 21
1.5.3	C-scan — 24
1.5.4	M-mode — 26
1.5.5	Shear wave sonography — 27
1.6	Scan characteristics — 28
1.6.1	Dynamic focusing — 28
1.6.2	Line density — 29
1.6.3	Scan frequency — 29
1.6.4	Depth of view — 30
1.6.5	Penetration depth — 30
1.6.6	Spatial resolution — 31
1.6.7	Axial resolution — 31
1.6.8	Lateral resolution — 31
1.6.9	Artifacts — 32
1.7	Doppler method — 33
1.7.1	Doppler shift — 33
1.7.2	cw Doppler method — 34

- 1.7.3 Pulsed Doppler method (duplex mode) — **38**
- 1.7.4 Duplex scan of umbilical cord — **40**
- 1.8 Summary — **42**
 - Exercises — **43**
 - Suggestion for home experiments — **45**
 - References — **45**
 - Further reading — **47**
 - Useful website — **47**

2 Endoscopy — 48

- 2.1 Introduction — **48**
- 2.2 Standard uses of medical endoscopes — **48**
- 2.3 Fiber optics — **50**
- 2.4 Endoscope optics — **54**
- 2.5 Resolution and magnification — **56**
- 2.6 Specialized endoscopes — **58**
 - 2.6.1 Narrowband imaging — **58**
 - 2.6.2 Chromoendoscopy — **60**
 - 2.6.3 Endomicroscopy — **60**
- 2.7 Confocal laser endoscopy — **60**
 - 2.7.1 General working principle — **60**
 - 2.7.2 Fiber-optic confocal reflectance microscope — **62**
- 2.8 Optical coherence tomography endoscopes — **63**
 - 2.8.1 Basic principle of OCT — **64**
 - 2.8.2 Resolution and scan range — **66**
 - 2.8.3 Additional methods and applications — **67**
- 2.9 Capsule endoscopy — **68**
- 2.10 Future trends — **69**
- 2.11 Summary — **71**
 - Suggestions for home experiment — **72**
 - Exercises — **73**
 - References — **73**
 - Further reading — **75**
 - Useful website — **75**

3 Magnetic resonance imaging — 76

- 3.1 Introduction — **77**
- 3.2 Nuclear spin basics — **77**
- 3.3 Nuclear magnetic resonance basics — **80**
 - 3.3.1 Zeeman splitting — **80**
 - 3.3.2 Equation of motion — **82**
 - 3.3.3 Magnetization of a two-level system — **83**

- 3.3.4 Toy model of magnetization relaxation — **86**
- 3.3.5 Resonance absorption — **88**
- 3.4 Spin-echo techniques — **92**
- 3.5 Autocorrelation and spectral density (for experts) — **96**
- 3.6 NMR and MRI procedures — **101**
 - 3.6.1 Saturation — **101**
 - 3.6.2 Chemical shift — **101**
 - 3.6.3 Standard nomenclature — **103**
- 3.7 Contrast generation — **105**
 - 3.7.1 T1 contrast — **105**
 - 3.7.2 T2 contrast — **107**
 - 3.7.3 PD contrast — **107**
 - 3.7.4 Inversion recovery (IR) — **110**
 - 3.7.5 Short time inversion recovery (STIR) — **111**
- 3.8 MR signal localization — **112**
 - 3.8.1 Slice encoding gradient — **113**
 - 3.8.2 Frequency encoding gradient (FEG) — **114**
 - 3.8.3 Phase encoding gradient (PEG) — **115**
 - 3.8.4 K-map — **116**
 - 3.8.5 Fourier transform — **118**
 - 3.8.6 Data acquisition — **119**
- 3.9 Magnets and coils — **120**
 - 3.9.1 Main coil — **121**
 - 3.9.2 Gradient coils — **122**
 - 3.9.3 rf-coils — **123**
- 3.9.4 MRI machine specifications — **123**
- 3.10 Applications of MRI — **126**
 - 3.10.1 Joints — **126**
 - 3.10.2 Dynamic contrast enhancement (DCE) MRI — **126**
 - 3.10.3 Angio-MRI — **130**
 - 3.10.4 Diffusion-weighted imaging (DWI) — **130**
 - 3.10.5 Multiple parameter MRI (mpMRI) — **133**
 - 3.10.6 Functional MRI (fMRI) — **133**
 - 3.10.7 Real-time MRI — **136**
- 3.11 Hyperpolarization MRI — **137**
 - 3.11.1 ³He-hMRI — **139**
 - 3.11.2 ¹³C-hMRI — **140**
 - 3.11.3 ¹⁷O-hMRI — **141**
 - 3.11.4 ¹⁹F-hMRI — **141**
- 3.12 Further remarks — **142**
 - 3.12.1 New trends and comparisons — **142**
 - 3.12.2 Advantages–disadvantages and hazards — **143**

- 3.13 Summary — 145
- Exercises — 148
- References — 148
- Further reading — 151
- Useful websites — 151

Part B: X-ray and nuclear methods

- 4 X-ray sources and generators — 155**
 - 4.1 Introduction — 155
 - 4.2 General components of x-ray tubes — 156
 - 4.3 Bremsstrahlung radiation — 158
 - 4.4 Characteristic radiation — 160
 - 4.4.1 Atomic transitions — 160
 - 4.4.2 Energy dispersive x-ray chemical analysis — 164
 - 4.4.3 Target material — 164
 - 4.5 X-ray generators — 166
 - 4.5.1 X-ray tubes for radiography — 166
 - 4.5.2 Linear accelerators for radiotherapy — 168
 - 4.5.3 Synchrotron radiation — 171
 - 4.6 Summary — 174
 - Exercises — 176
 - References — 176
 - Further reading — 177
 - Useful website — 177

- 5 Nuclei and isotopes — 178**
 - 5.1 Introduction — 178
 - 5.2 Isotopes — 179
 - 5.3 Atomic mass and atomic weight — 181
 - 5.4 Nuclear decay — 183
 - 5.4.1 Electron emission (β^-) — 184
 - 5.4.2 Positron emission (β^+) — 184
 - 5.4.3 Electron capture (EC) — 186
 - 5.4.4 α -Particle decay — 187
 - 5.4.5 Decay schemes — 187
 - 5.5 Radioactivity — 189
 - 5.5.1 Exponential decay law — 189
 - 5.5.2 Nuclear activity — 192
 - 5.5.3 Decay chains — 194
 - 5.6 Radioisotope production — 195

- 5.6.1 Nuclear reactions — 196
- 5.6.2 Isotope production via irradiation — 196
- 5.6.3 Charge particle activation — 198
- 5.6.4 Cyclotron isotope production — 200
- 5.6.5 Radioisotope production by fission — 205
- 5.6.6 Neutron activation — 206
- 5.7 Summary — 208
- Exercises — 210
- References — 212
- Further reading — 212

- 6 Interaction of radiation with matter — 214**
 - 6.1 Attenuation: Lambert-Beer law — 214
 - 6.2 Interaction of EM radiation with matter — 216
 - 6.2.1 Attenuation coefficient of photons — 216
 - 6.2.2 Mass attenuation coefficient of photons — 218
 - 6.2.3 Photoelectric effect — 219
 - 6.2.4 Compton scattering — 221
 - 6.2.5 Coherent scattering of x-rays — 226
 - 6.2.6 Pair production — 229
 - 6.2.7 Comparison of photon–electron interactions — 230
 - 6.3 Interaction of charged particles with matter — 231
 - 6.3.1 Alpha particles — 231
 - 6.3.2 Beta-particles — 235
 - 6.4 Interaction of neutrons with matter — 237
 - 6.5 Summary — 240
 - Suggestion for home experiment — 241
 - Exercises — 242
 - References — 243
 - Further reading — 243
 - Useful website — 243

- 7 Dosimetry — 244**
 - 7.1 Introduction — 244
 - 7.2 Definitions of dose and dose rate — 245
 - 7.3 Kerma — 249
 - 7.3.1 Flux and fluence — 249
 - 7.3.2 Energy fluence — 249
 - 7.3.3 Mass energy transfer coefficient — 250
 - 7.3.4 Mass energy absorption coefficient — 250
 - 7.3.5 Definition of kerma — 251
 - 7.3.6 Examples — 253

7.4	Dosimeters and radiation monitors —	255
7.4.1	Ionization chamber —	256
7.4.2	Proportional counters —	256
7.4.3	Geiger-Müller detectors —	258
7.4.4	Dead time —	258
7.5	Radiation exposure —	259
7.6	Radiation protection —	260
7.7	Summary —	262
	Suggestions for home experiment —	263
	Exercises —	264
	References —	265
	Further reading —	265

Part C: Radiography

8	X-ray radiography —	269
8.1	Introduction —	269
8.2	Standard x-ray radiography —	270
8.2.1	Beam delivery and beam hardening —	270
8.2.2	Magnification and penumbra —	272
8.2.3	Compton scattering and grids —	273
8.3	X-ray attenuation and contrast —	275
8.3.1	Contrast —	275
8.3.2	Attenuation profile —	277
8.4	X-ray recording —	279
8.4.1	Film radiography —	279
8.4.2	Fluoroscopy —	282
8.4.3	Flat panel radiography —	284
8.4.4	Comparison —	286
8.5	Counting statistics, noise, quantum efficiency —	287
8.5.1	Counting statistics —	287
8.5.2	Noise and quantum efficiency —	288
8.6	System integration —	290
8.6.1	Projection radiography —	290
8.6.2	Mammography —	292
8.7	Attenuation contrast enhancement —	292
8.7.1	Contrast agents —	293
8.7.2	Digital subtraction angiography (DSA) —	295
8.7.3	Dual-energy x-ray absorptiometry —	295
8.8	Phase contrast imaging (PCI) —	298
8.8.1	Physical background —	298

- 8.8.2 Detection of phase contrast — 300
- 8.9 Computed tomography (CT) — 303
 - 8.9.1 Overview — 303
 - 8.9.2 The Hounsfield scale — 304
 - 8.9.3 Specifications of CT scanners — 306
 - 8.9.4 Contrast enhancement — 309
 - 8.9.5 Radon transformation — 310
 - 8.9.6 Backprojection — 313
 - 8.9.7 Filter — 314
- 8.10 Risks and comparisons — 318
- 8.11 Summary — 319
 - Exercises — 321
 - References — 323
 - Further reading — 324
 - Useful website — 324

- 9 Scintigraphy (SPE and SPECT) — 325**
 - 9.1 Introduction — 325
 - 9.2 Collimators for scintigraphy — 326
 - 9.3 Detectors, counting, and artifacts — 329
 - 9.3.1 Photomultiplier tube — 329
 - 9.3.2 Anger counting — 331
 - 9.3.3 CZT detectors — 331
 - 9.3.4 Artifacts: Compton scattering — 333
 - 9.3.5 SNR and CNR — 334
 - 9.4 Isotopes for scintigraphy — 335
 - 9.4.1 Radioisotopes and radiopharmaceuticals — 335
 - 9.4.2 Isotope generators — 337
 - 9.5 Full body SPE scans — 339
 - 9.6 Single-photon emission computed tomography (SPECT) — 341
 - 9.6.1 SPECT systems and detectors — 341
 - 9.6.2 Clinical applications — 343
 - 9.6.3 SPECT image processing — 345
 - 9.7 Summary — 346
 - Exercises — 347
 - References — 348
 - Further reading — 349

- 10 Positron emission tomography — 350**
 - 10.1 Introduction — 350
 - 10.2 Basic principle of PET — 351
 - 10.2.1 Energy and momentum — 351

10.2.2	Coincidence counting —	352
10.2.3	Artifacts —	353
10.2.4	Spatial resolution —	354
10.2.5	TOF-PET —	355
10.2.6	Ring designs —	356
10.2.7	PET scanner and combinations —	357
10.3	Data acquisition and image reconstruction —	358
10.3.1	Detectors —	358
10.3.2	Counting statistics —	359
10.3.3	Image reconstruction —	359
10.3.4	Standard uptake value —	360
10.4	PET isotopes —	361
10.4.1	General aspects —	361
10.4.2	^{18}F -decay —	362
10.5	Clinical applications of PET —	364
10.5.1	FDG-PET —	364
10.5.2	FET-PET —	366
10.5.3	Prostate-specific membrane antigen PET —	367
10.6	Conclusion —	369
10.7	Summary —	370
	Exercises —	372
	References —	373
	Useful websites —	374
	Further reading —	374

Appendix

11	Answers to questions —	377
12	Solutions to exercises —	389
13	List of acronyms (used in all three volumes) —	415
14	Selection of fundamental physical constants, conversions, and relationships —	418
15	List of scientists named in this volume —	419
16	Glossary —	420
17	Index of terms —	423