

CONTENTS IN BRIEF

PREFACE	xv	19	ULTRASOUND WAVES	303	
PREFACE TO THE FIRST EDITION	xvii	20	ULTRASOUND TRANSDUCERS	317	
ACKNOWLEDGMENTS	xix	21	ULTRASOUND INSTRUMENTATION	331	
1	IMAGING IN MEDICINE	1	22	DOPPLER EFFECT	343
2	STRUCTURE OF MATTER	11	23	FUNDAMENTALS OF MAGNETIC RESONANCE	355
3	RADIOACTIVE DECAY	27	24	MAGNETIC RESONANCE IMAGING AND SPECTROSCOPY	367
4	INTERACTIONS OF RADIATION	45	25	MAGNETIC RESONANCE IMAGING: INSTRUMENTATION, BIOEFFECTS, AND SITE PLANNING	389
5	PRODUCTION OF X RAYS	69	26	EXPERIMENTAL RADIOBIOLOGY	403
6	RADIATION QUANTITY AND QUALITY	91	27	HUMAN RADIOBIOLOGY	413
7	INTERACTION OF X AND γ RAYS IN THE BODY	117	28	PROTECTION FROM EXTERNAL SOURCES OF RADIATION	435
8	RADIATION DETECTORS FOR QUANTITATIVE MEASUREMENT	127	29	PROTECTION FROM INTERNAL SOURCES OF RADIATION	455
9	ACCUMULATION AND ANALYSIS OF NUCLEAR DATA	143	30	FUTURE DEVELOPMENTS IN MEDICAL IMAGING	467
10	COMPUTERS AND IMAGE NETWORKING	161	APPENDIX I	REVIEW OF MATHEMATICS	477
11	PROBABILITY AND STATISTICS	179	APPENDIX II	FOURIER TRANSFORM	483
12	INSTRUMENTATION FOR NUCLEAR IMAGING	197	APPENDIX III	MULTIPLES AND PREFIXES	485
13	RADIOGRAPHY	217	APPENDIX IV	MASSES IN ATOMIC MASS UNITS FOR NEUTRAL ATOMS OF STABLE NUCLIDES AND A FEW UNSTABLE NUCLIDES	487
14	FLUOROSCOPY	235	ANSWERS TO SELECTED PROBLEMS	491	
15	COMPUTED TOMOGRAPHY	251	INDEX	495	
16	INFLUENCES ON IMAGE QUALITY	265			
17	ANALYTIC DESCRIPTION OF IMAGE QUALITY	281			
18	VISUAL PERCEPTION	289			

CONTENTS

PREFACE xv

PREFACE TO THE FIRST EDITION xvii

ACKNOWLEDGMENTS xix

1 ■ IMAGING IN MEDICINE 1

OBJECTIVES 2

INTRODUCTION 2

CONCLUSIONS 9

REFERENCES 9

2 ■ STRUCTURE OF MATTER 11

OBJECTIVES 12

THE ATOM 12

SOLIDS 17

SUPERCONDUCTIVITY 18

THE NUCLEUS 19

NUCLEAR FISSION AND FUSION 21

NUCLEAR SPIN AND NUCLEAR MAGNETIC MOMENTS 22

NUCLEAR NOMENCLATURE 23

PROBLEMS 23

SUMMARY 24

REFERENCES 25

3 ■ RADIOACTIVE DECAY 27

OBJECTIVES 28

NUCLEAR STABILITY AND DECAY 28

ALPHA DECAY 29

DECAY SCHEMES 29

BETA DECAY 30

ISOMERIC TRANSITIONS 33

MATHEMATICS OF RADIOACTIVE DECAY 33

DECAY EQUATIONS AND HALF-LIFE 35

TRANSIENT EQUILIBRIUM 37

ARTIFICIAL PRODUCTION OF RADIONUCLIDES 39

MATHEMATICS OF NUCLIDE PRODUCTION BY NEUTRON BOMBARDMENT 40

INFORMATION ABOUT RADIOACTIVE NUCLIDES 41

PROBLEMS 41

SUMMARY 42

REFERENCES 43

4 ■ INTERACTIONS OF RADIATION 45

OBJECTIVES 46

CHARACTERISTICS OF INTERACTIONS 46

DIRECTLY IONIZING RADIATION 46

INTERACTIONS OF ELECTRONS 48

INTERACTIONS OF HEAVY, CHARGED PARTICLES 50

INDIRECTLY IONIZING RADIATION 50

INTERACTIONS OF NEUTRONS 50

ATTENUATION OF X AND γ RADIATION 51

NONIONIZING RADIATION 64

INTERACTIONS OF NONIONIZING ELECTROMAGNETIC RADIATION 66

PROBLEMS 67

SUMMARY 67

REFERENCES 68

5 ■ PRODUCTION OF X RAYS 69

OBJECTIVES 70

INTRODUCTION 70

CONVENTIONAL X-RAY TUBES 70

ELECTRON SOURCE 70

TUBE VOLTAGE AND VOLTAGE WAVEFORMS 71

RELATIONSHIP BETWEEN FILAMENT CURRENT AND TUBE CURRENT 73
EMISSION SPECTRA 73
FILTRATION 74
TUBE VACUUM 79
ENVELOPE AND HOUSING 79
SPECIAL-PURPOSE X-RAY TUBES 81
RATINGS FOR X-RAY TUBES 82
PROBLEMS 88
SUMMARY 88
REFERENCES 89

6 ■ RADIATION QUANTITY AND QUALITY 91

OBJECTIVES 92
INTENSITY 92
TRADITIONAL VERSUS SYSTÈME INTERNATIONAL UNITS 94
RADIATION EXPOSURE 95
UNITS OF RADIATION DOSE 98
DOSE EQUIVALENT 100
MEASUREMENT OF RADIATION DOSE 102
HALF-VALUE LAYER 111
VARIATION IN QUALITY ACROSS AN X-RAY BEAM 112
SPECTRAL DISTRIBUTION OF AN X-RAY BEAM 113
PROBLEMS 113
SUMMARY 114
REFERENCES 115

7 ■ INTERACTION OF X AND γ RAYS IN THE BODY 117

OBJECTIVES 118
INTRODUCTION 118
F FACTOR 118
ATTENUATION OF X AND γ RAYS IN TISSUE 119
DOSE TO SOFT TISSUE BEYOND BONE 121
HIGH-VOLTAGE RADIOGRAPHY 122
LOW-VOLTAGE RADIOGRAPHY 122
CONTRAST MEDIA 123
PROBLEMS 125

SUMMARY 125
REFERENCES 125

8 ■ RADIATION DETECTORS FOR QUANTITATIVE MEASUREMENT 127

OBJECTIVES 128
IONIZATION CHAMBERS 128
PROPORTIONAL COUNTERS 131
GEIGER-MÜLLER TUBES 132
SOLID SCINTILLATION DETECTORS 134
LIQUID SCINTILLATION DETECTORS 136
SEMICONDUCTOR RADIATION DETECTORS 138
PROBLEMS 140
SUMMARY 140
REFERENCES 141

9 ■ ACCUMULATION AND ANALYSIS OF NUCLEAR DATA 143

OBJECTIVES 144
INTRODUCTION 144
COUNTING SYSTEMS 144
DETERMINATE ERRORS IN RADIOACTIVITY MEASUREMENTS 149
GAMMA-RAY SPECTROMETRY 152
PULSE HEIGHT SPECTRA 152
PHOTOPEAK COUNTING 156
RADIOACTIVE AGENTS FOR CLINICAL STUDIES 157
PROBLEMS 158
SUMMARY 159
REFERENCES 160

10 ■ COMPUTERS AND IMAGE NETWORKING 161

OBJECTIVES 162
HISTORY 162
MACHINE REPRESENTATION OF DATA 163
COMPUTER SYSTEM HARDWARE 168
SOFTWARE 173
NETWORKING 173
PROBLEMS 177

SUMMARY 177
REFERENCES 178

11 ■ PROBABILITY AND STATISTICS 179

OBJECTIVES 180
INTRODUCTION 180
NATURE OF ERROR 180
PROBABILITY DISTRIBUTIONS 181
SIGNAL AND NOISE 183
METHODS TO DESCRIBE PROBABILITY DISTRIBUTIONS 184
PROPAGATION OF ERROR 188
OTHER METHODS FOR DESCRIBING PRECISION 190
SELECTED STATISTICAL TESTS 192
SUMMARY 195
PROBLEMS 195
REFERENCES 195

12 ■ INSTRUMENTATION FOR NUCLEAR IMAGING 197

OBJECTIVES 198
INTRODUCTION 198
MEASUREMENT OF ACCUMULATION AND EXCRETION RATES 198
SINGLE-CRYSTAL SCINTILLATION CAMERA 201
PRINCIPLES OF SCINTILLATION CAMERA OPERATION 202
MULTIPLE-CRYSTAL SCINTILLATION CAMERA 209
SOLID-STATE CAMERA 209
RECTILINEAR SCANNER 210
EMISSION COMPUTED TOMOGRAPHY 210
PROBLEMS 214
SUMMARY 215
REFERENCES 215

13 ■ RADIOGRAPHY 217

OBJECTIVES 218
X-RAY FILM 218
INTENSIFYING SCREENS 223
RADIOGRAPHIC GRIDS 226
MAGNIFICATION RADIOGRAPHY 229

DIGITAL RADIOGRAPHY 230
PROBLEMS 233
SUMMARY 234
REFERENCES 234

14 ■ FLUOROSCOPY 235

OBJECTIVES 236
FLUOROSCOPY AND IMAGE INTENSIFICATION 236
TELEVISION DISPLAY OF THE FLUOROSCOPIC IMAGE 241
DIGITAL FLUOROSCOPY 244
AUTOMATIC BRIGHTNESS CONTROL 245
CINEFLUOROGRAPHY 247
PROBLEMS 248
SUMMARY 249
REFERENCES 249

15 ■ COMPUTED TOMOGRAPHY 251

OBJECTIVES 252
INTRODUCTION 252
HISTORY 252
PRINCIPLE OF COMPUTED TOMOGRAPHIC IMAGING 253
RECONSTRUCTION ALGORITHMS 254
SCAN MOTIONS 255
X-RAY SOURCES 258
COLLIMATION 258
X-RAY DETECTORS 258
VIEWING SYSTEMS 258
PATIENT DOSE 259
QUALITY CONTROL 260
SUMMARY 262
PROBLEMS 262
REFERENCES 262

16 ■ INFLUENCES ON IMAGE QUALITY 265

OBJECTIVES 266
INTRODUCTION 266
UNSHARPNESS 266
CONTRAST 270

IMAGE NOISE 274

IMAGE DISTORTION AND ARTIFACTS 276

SUMMARY 278

PROBLEMS 278

REFERENCES 279

17 ■ ANALYTIC DESCRIPTION OF IMAGE QUALITY 281

OBJECTIVES 282

INTRODUCTION 282

POINT RESPONSE 282

LINE RESPONSE 282

CONTRAST RESPONSE 283

MODULATION TRANSFER FUNCTION 284

QUANTUM LEVELS AND CONVERSION EFFICIENCIES 286

SUMMARY 286

PROBLEMS 287

REFERENCES 287

18 ■ VISUAL PERCEPTION 289

OBJECTIVES 290

INTRODUCTION 290

HUMAN VISION 292

DETECTION OF VISUAL INFORMATION 295

VISUAL ACUITY 296

CONTRAST DISCRIMINATION 296

RECOGNITION AND INTERPRETATION OF VISUAL INFORMATION 298

EXPRESSIONS OF VISUAL PERFORMANCE 298

SUMMARY 300

PROBLEMS 301

REFERENCES 301

19 ■ ULTRASOUND WAVES 303

OBJECTIVES 304

INTRODUCTION 304

HISTORY 304

WAVE MOTION 304

WAVE CHARACTERISTICS 305

ULTRASOUND INTENSITY 306

ULTRASOUND VELOCITY 307

ATTENUATION OF ULTRASOUND 308

REFLECTION 311

REFRACTION 313

ABSORPTION 314

SUMMARY 315

PROBLEMS 316

REFERENCES 316

20 ■ ULTRASOUND TRANSDUCERS 317

OBJECTIVES 318

INTRODUCTION 318

PIEZOELECTRIC EFFECT 318

TRANSDUCER DESIGN 319

FREQUENCY RESPONSE OF TRANSDUCERS 320

ULTRASOUND BEAMS 321

PROBLEMS 329

SUMMARY 329

REFERENCES 329

21 ■ ULTRASOUND INSTRUMENTATION 331

OBJECTIVES 332

PRESENTATION MODES 332

TIME REQUIRED TO OBTAIN IMAGES 333

SYSTEM COMPONENTS 335

SIGNAL PROCESSING 335

DYNAMIC RANGE 337

ULTRASOUND IMAGE ARTIFACTS 338

QUALITY CONTROL 338

PROBLEMS 340

SUMMARY 341

REFERENCES 341

22 ■ DOPPLER EFFECT 343

OBJECTIVES 344

ORIGIN OF DOPPLER SHIFT 344

LIMITATIONS OF DOPPLER SYSTEMS 351

PROBLEMS 352

SUMMARY 352

REFERENCES 353

23 ■ FUNDAMENTALS OF MAGNETIC RESONANCE 355

- OBJECTIVES 356
- INTERACTION OF NUCLEI WITH A STATIC MAGNETIC FIELD 356
- ROTATION AND PRECESSION 356
- INTERACTION OF NUCLEI WITH A RADIO FREQUENCY WAVE: NUTATION 357
- INDUCTION OF A MAGNETIC RESONANCE SIGNAL IN A COIL 358
- QUANTUM MECHANICAL INTERPRETATION 359
- BULK MAGNETIZATION 360
- RELAXATION PROCESSES: T1 AND T2 361
- RELAXATION TIMES (T1 AND T2) FOR BIOLOGIC MATERIALS 363
- PROBLEMS 364
- SUMMARY 364
- REFERENCES 364

24 ■ MAGNETIC RESONANCE IMAGING AND SPECTROSCOPY 367

- OBJECTIVES 368
- OVERVIEW: MAGNETIC RESONANCE AS A PROBE OF THE BODY 368
- PULSE SEQUENCES 368
- SPATIAL ENCODING OF MAGNETIC RESONANCE IMAGING SIGNAL 370
- MOTION SUPPRESSION TECHNIQUES 374
- CONTRAST AGENTS 376
- TISSUE CONTRAST IN MAGNETIC RESONANCE IMAGING 377
- MR ANGIOGRAPHY 380
- SPECTROSCOPY 380
- CHEMICAL SHIFT IMAGING 383
- PROBLEMS 384
- SUMMARY 384
- REFERENCES 385

25 ■ MAGNETIC RESONANCE IMAGING: INSTRUMENTATION, BIOEFFECTS, AND SITE PLANNING 389

- OBJECTIVES 390
- MAIN SYSTEM MAGNET 390
- GRADIENT MAGNETIC FIELDS 391

- RADIO-FREQUENCY COILS 391
- ELECTRONIC COMPONENTS 392
- COMPUTER 393
- ARTIFACTS 393
- QUALITY ASSURANCE 395
- BIOEFFECTS 395
- SITE PLANNING 398
- SUMMARY 400
- REFERENCES 401

26 ■ EXPERIMENTAL RADIOBIOLOGY 403

- OBJECTIVES 404
- INTRODUCTION 404
- INTERACTIONS AT THE CELL AND TISSUE LEVELS 405
- CELL SURVIVAL STUDIES 405
- MODIFICATION OF CELLULAR RESPONSES 406
- ANIMAL STUDIES 409
- CONCLUSIONS 411
- REFERENCES 411

27 ■ HUMAN RADIOBIOLOGY 413

- OBJECTIVES 414
- STOCHASTIC EFFECTS OF RADIATION 414
- NONSTOCHASTIC EFFECTS OF RADIATION 414
- DOSIMETRY IN INDIVIDUALS AND POPULATIONS 416
- BACKGROUND RADIATION 417
- HUMAN POPULATIONS THAT HAVE BEEN EXPOSED TO UNUSUAL LEVELS OF RADIATION 419
- DOSE-EFFECT MODELS 423
- FACTORS THAT INFLUENCE DOSE-EFFECT MODELS 425
- ESTIMATING RISKS OF RADIATION: BEIR REPORT 426
- SOURCES OF INFORMATION 429
- SUMMARY 431
- REFERENCES 431

28 ■ PROTECTION FROM EXTERNAL SOURCES OF RADIATION 435

- OBJECTIVES 436
- REGULATORY AUTHORITY FOR RADIATION PROTECTION 437

EFFECTIVE DOSE LIMITS 438
SAFETY RECOMMENDATIONS FOR SOURCES OF X AND γ RADIATION 442
PROTECTIVE BARRIERS FOR RADIATION SOURCES 442
AREA AND PERSONNEL MONITORING 450
PROBLEMS 452
SUMMARY 452
REFERENCES 453

29 ■ PROTECTION FROM INTERNAL SOURCES OF RADIATION 455

OBJECTIVES 456
INTRODUCTION 456
COMMITTED DOSE EQUIVALENT 456
ESTIMATING INTERNAL DOSE 457
RADIATION DOSE FROM INTERNAL RADIOACTIVITY 458
RECOMMENDATIONS FOR SAFE USE OF RADIOACTIVE NUCLIDES 465
SUMMARY 465
REFERENCES 465

30 ■ FUTURE DEVELOPMENTS IN MEDICAL IMAGING 467

OBJECTIVES 468
INTRODUCTION 468

NEW IMAGING TECHNOLOGIES 468
PHASE-CONTRAST X-RAY IMAGING 471
INFORMATION MANAGEMENT AND COMMUNICATION 471
TECHNOLOGY ASSESSMENT 473
TECHNICAL EXPERTISE IN RADIOLOGY 474
SUMMARY 474
REFERENCES 475

■ APPENDIX I

REVIEW OF MATHEMATICS 477

■ APPENDIX II

FOURIER TRANSFORM 483
DOPPLER ULTRASOUND 483
MAGNETIC RESONANCE 483

■ APPENDIX III

MULTIPLES AND PREFIXES 485

■ APPENDIX IV

MASSES IN ATOMIC MASS UNITS FOR NEUTRAL ATOMS OF STABLE NUCLIDES AND A FEW UNSTABLE NUCLIDES 487

ANSWERS TO SELECTED PROBLEMS 491
INDEX 495