
Contents

1	Mechanics	1
1.1	Distances and Sizes	1
1.2	Models	3
1.3	Forces and Translational Equilibrium	3
1.4	Rotational Equilibrium	4
1.5	Vector Product	6
1.6	Force in the Achilles Tendon	6
1.7	Forces on the Hip	7
1.8	The Use of a Cane	10
1.9	Work	11
1.10	Stress and Strain	12
1.11	Shear	13
1.12	Hydrostatics	13
1.13	Buoyancy	15
1.14	Compressibility	15
1.15	Diving	15
1.16	Viscosity	15
1.17	Viscous Flow in a Tube	16
1.18	Pressure–Volume Work	19
1.19	The Human Circulatory System	20
1.20	Turbulent Flow and the Reynolds Number	22
	Symbols Used	24
	Problems	25
	References	30
2	Exponential Growth and Decay	33
2.1	Exponential Growth	33
2.2	Exponential Decay	35
2.3	Semilog Paper	36
2.4	Variable Rates	38
2.5	Clearance	40
2.6	The Chemostat	40
2.7	Multiple Decay Paths	41
2.8	Decay Plus Input at a Constant Rate	41
2.9	Decay With Multiple Half-Lives and Fitting Exponentials	41
2.10	The Logistic Equation	42

2.11	Log-log Plots, Power Laws, and Scaling	43
2.11.1	Log-log Plots and Power Laws	43
2.11.2	Food Consumption, Basal Metabolic Rate, and Scaling	44
	Symbols Used	45
	Problems	45
	References	51
3	Systems of Many Particles	53
3.1	Gas Molecules in a Box	54
3.2	Microstates and Macrostates	56
3.3	The Energy of a System: The First Law of Thermodynamics	57
3.4	Ensembles and the Basic Postulates	59
3.5	Thermal Equilibrium	60
3.6	Entropy	62
3.7	The Boltzmann Factor	62
3.8	The Nernst Equation	63
3.9	The Pressure Variation in the Atmosphere	64
3.10	Equipartition of Energy and Brownian Motion	64
3.11	Heat Capacity	65
3.12	Equilibrium When Particles Can Be Exchanged: the Chemical Potential	66
3.13	Concentration Dependence of the Chemical Potential	67
3.14	Systems That Can Exchange Volume	68
3.15	Extensive Variables and Generalized Forces	68
3.16	The General Thermodynamic Relationship	69
3.17	The Gibbs Free Energy	70
3.17.1	Gibbs Free Energy	70
3.17.2	An Example: Chemical Reactions	71
3.18	The Chemical Potential of a Solution	72
3.19	Transformation of Randomness to Order	74
	Symbols Used	75
	Problems	76
	References	83
4	Transport in an Infinite Medium	85
4.1	Flux, Fluence, and Continuity	85
4.1.1	The Continuity Equation in One Dimension	86
4.1.2	The Continuity Equation in Three Dimensions	86
4.1.3	The Integral Form of the Continuity Equation	87
4.1.4	The Differential Form of the Continuity Equation	88
4.1.5	The Continuity Equation with a Chemical Reaction	89
4.2	Drift or Solvent Drag	89
4.3	Brownian Motion	89
4.4	Motion in a Gas: Mean Free Path and Collision Time	90
4.5	Motion in a Liquid	91
4.6	Diffusion: Fick's First Law	92
4.7	The Einstein Relationship Between Diffusion and Viscosity	93
4.8	Fick's Second Law of Diffusion	95
4.9	Time-Independent Solutions	97
4.10	Example: Steady-State Diffusion to a Spherical Cell and End Effects	98
4.10.1	Diffusion Through a Collection of Pores, Corrected	100
4.10.2	Diffusion from a Sphere, Corrected	100
4.10.3	How Many Pores Are Needed?	100
4.10.4	Other Applications of the Model	101

4.11	Example: A Spherical Cell Producing a Substance	101
4.12	Drift and Diffusion in One Dimension	102
4.13	A General Solution for the Particle Concentration as a Function of Time	104
4.14	Diffusion as a Random Walk	105
	Symbols Used	107
	Problems	108
	References	114
5	Transport Through Neutral Membranes	117
5.1	Membranes	117
5.2	Osmotic Pressure in an Ideal Gas	118
5.3	Osmotic Pressure in a Liquid	120
5.4	Some Clinical Examples	121
5.4.1	Edema Due to Heart Failure	122
5.4.2	Nephrotic Syndrome, Liver Disease, and Ascites	122
5.4.3	Edema of Inflammatory Reaction	122
5.4.4	Headaches in Renal Dialysis	123
5.4.5	Osmotic Diuresis	123
5.4.6	Osmotic Fragility of Red Cells	123
5.5	Volume Transport Through a Membrane	123
5.6	Solute Transport Through a Membrane	125
5.7	Example: The Artificial Kidney	126
5.8	Countercurrent Transport	127
5.9	A Continuum Model for Volume and Solute Transport in a Pore	128
5.9.1	Volume Transport	128
5.9.2	Solute Transport	130
5.9.3	Summary	133
5.9.4	Reflection Coefficient	133
5.9.5	The Effect of Pore Walls on Diffusion	134
5.9.6	Net Force on the Membrane	134
	Symbols Used	135
	Problems	135
	References	139
6	Impulses in Nerve and Muscle Cells	141
6.1	Physiology of Nerve and Muscle Cells	141
6.2	Coulomb's Law, Superposition, and the Electric Field	143
6.3	Gauss's Law	144
6.4	Potential Difference	147
6.5	Conductors	148
6.6	Capacitance	149
6.7	Dielectrics	149
6.8	Current and Ohm's Law	151
6.9	The Application of Ohm's Law to Simple Circuits	153
6.10	Charge Distribution in the Resting Nerve Cell	154
6.11	The Cable Model for an Axon	155
6.12	Electrotonus or Passive Spread	159
6.13	The Hodgkin–Huxley Model for Membrane Current	160
6.13.1	Voltage Clamp Experiments	161
6.13.2	Potassium Conductance	163
6.13.3	Sodium Conductance	164
6.13.4	Leakage Current	165

6.14	Voltage Changes in a Space-Clamped Axon	165
6.15	Propagating Nerve Impulse	166
6.16	Myelinated Fibers and Saltatory Conduction	167
6.17	Membrane Capacitance	169
6.18	Rhythmic Electrical Activity	172
6.19	The Relationship Between Capacitance, Resistance, and Diffusion	172
6.19.1	Capacitance and Resistance	172
6.19.2	Capacitance and Diffusion	173
	Symbols Used	174
	Problems	175
	References	183
7	The Exterior Potential and the Electrocardiogram	185
7.1	The Potential Outside a Long Cylindrical Axon	185
7.2	The Exterior Potential is Small	187
7.3	The Potential Far from the Axon	188
7.4	The Exterior Potential for an Arbitrary Pulse	189
7.5	Electrical Properties of the Heart	193
7.6	The Current-Dipole Vector of the Heart as a Function of Time	195
7.7	The Electrocardiographic Leads	195
7.8	Some Electrocardiograms	198
7.9	Refinements to the Model	199
7.9.1	The Fiber Has a Finite Radius	200
7.9.2	Nonuniform Exterior Conductivity	200
7.9.3	Anisotropic Conductivity: The Bidomain Model	200
7.10	Electrical Stimulation	201
7.11	The Electroencephalogram	205
	Symbols Used	206
	Problems	206
	References	211
8	Biomagnetism	213
8.1	The Magnetic Force on a Moving Charge	213
8.1.1	The Lorentz Force	213
8.1.2	The Cyclotron	215
8.2	The Magnetic Field of a Moving Charge or a Current	215
8.2.1	The Divergence of the Magnetic Field is Zero	215
8.2.2	Ampere's Circuital Law	216
8.2.3	The Biot–Savart Law	216
8.2.4	The Displacement Current	217
8.3	The Magnetic Field Around an Axon	218
8.4	The Magnetocardiogram	219
8.5	The Magnetoencephalogram	223
8.6	Electromagnetic Induction	224
8.7	Magnetic Stimulation	225
8.8	Magnetic Materials and Biological Systems	226
8.8.1	Magnetic Materials	226
8.8.2	Measuring Magnetic Properties in People	228
8.8.3	Magnetic Orientation	228
8.8.4	Magnetic Nanoparticles	229
8.9	Detection of Weak Magnetic Fields	229
	Symbols Used	231
	Problems	231
	References	236

9	Electricity and Magnetism at the Cellular Level	239
9.1	Donnan Equilibrium	239
9.2	Potential Change at an Interface: The Gouy–Chapman Model	241
9.3	Ions in Solution: The Debye–Hückel Model	244
9.4	Saturation of the Dielectric	245
9.5	Ion Movement in Solution: The Nernst–Planck Equation	247
9.6	Zero Total Current in a Constant-Field Membrane: The Goldman Equations	249
9.7	Membrane Channels	250
9.8	Noise	254
9.8.1	Shot Noise	254
9.8.2	Johnson Noise	255
9.9	Sensory Transducers	256
9.10	Possible Effects of Weak External Electric and Magnetic Fields	256
9.10.1	Strong Fields	257
9.10.2	Power Frequency (50–60 Hz) Fields	257
9.10.2.1	Fields in Homes are Weak	257
9.10.2.2	Epidemiological Studies	257
9.10.2.3	Laboratory Studies	258
9.10.2.4	Reviews and Panel Reports	258
9.10.2.5	Electric Fields in the Body	258
9.10.2.6	Electric Fields in a Spherical Cell	259
9.10.3	Electrical Interactions and Noise	259
9.10.4	Magnetic Interactions and Noise	260
9.10.5	Microwaves, Mobile Phones, and Wi-Fi	261
	Symbols Used	262
	Problems	263
	References	266
10	Feedback and Control	269
10.1	Steady-State Relationships Among Variables	270
10.2	Determining the Operating Point	271
10.3	Regulation of a Variable and Open-Loop Gain	271
10.4	Approach to Equilibrium without Feedback	273
10.5	Approach to Equilibrium in a Feedback Loop with One Time Constant	273
10.6	A Feedback Loop with Two Time Constants	276
10.7	Proportional, Derivative, and Integral Control	278
10.8	Models Using Nonlinear Differential Equations	279
10.8.1	Describing a Nonlinear System	280
10.8.2	An Example of Phase Resetting: The Radial Isochron Clock	281
10.8.3	Stopping an Oscillator	283
10.9	Difference Equations and Chaotic Behavior	284
10.9.1	The Logistic Map: Period Doubling and Deterministic Chaos	284
10.9.2	The Bifurcation Diagram	285
10.9.3	Quasiperiodicity	286
10.10	A Feedback Loop with a Time Constant and a Fixed Delay	287
10.11	Negative Feedback Loops: A Summary	288
10.12	Additional Examples	289
10.12.1	Cheyne–Stokes Respiration	289
10.12.2	Hot Tubs and Heat Stroke	289
10.12.3	Pupil Size	289
10.12.4	Oscillating White-Blood-Cell Counts	290

10.12.5	Waves in Excitable Media	290
10.12.6	Period Doubling and Chaos in Heart Cells	291
	Symbols Used	292
	Problems	292
	References	300
11	The Method of Least Squares and Signal Analysis	303
11.1	The Method of Least Squares and Polynomial Regression	303
11.1.1	The Simplest Example	303
11.1.2	A Linear Fit	304
11.1.3	A Polynomial Fit	305
11.1.4	Variable Weighting	306
11.2	Nonlinear Least Squares	306
11.3	The Presence of Many Frequencies in a Periodic Function	308
11.4	Fourier Series for Discrete Data	308
11.4.1	Determining the Parameters	309
11.4.2	Equally Spaced Data Points Simplify the Equations	310
11.4.3	The Standard Form for the Discrete Fourier Transform	310
11.4.4	Complex Exponential Notation	311
11.4.5	Example: The Square Wave	311
11.4.6	Example: When the Sampling Time is not a Multiple of the Period of the Signal	312
11.4.7	Example: Spontaneous Births	313
11.4.8	Example: Photosynthesis in Plants	314
11.4.9	Pitfalls of Discrete Sampling: Aliasing	314
11.4.10	Fast Fourier Transform	315
11.5	Fourier Series for a Periodic Function	315
11.6	The Power Spectrum	317
11.7	Correlation Functions	317
11.7.1	Cross-Correlation of a Pulse	318
11.7.2	Cross-Correlation of a Nonpulse Signal	318
11.7.3	Cross-Correlation Example	318
11.7.4	Autocorrelation	318
11.7.5	Autocorrelation Examples	319
11.8	The Autocorrelation Function and the Power Spectrum	320
11.9	Nonperiodic Signals and Fourier Integrals	320
11.9.1	Introduce Negative Frequencies and Make the Coefficients Half as Large	321
11.9.2	Make the Period Infinite	322
11.9.3	Complex Notation	322
11.9.4	Example: The Exponential Pulse	322
11.10	The Delta Function	323
11.11	The Energy Spectrum of a Pulse and Parseval's Theorem	324
11.11.1	Parseval's Theorem	324
11.11.2	Example: The Exponential Pulse	325
11.12	The Autocorrelation of a Pulse and its Relation to the Energy Spectrum	325
11.13	Noise	326
11.14	Correlation Functions and Noisy Signals	327
11.14.1	Detecting Signals in Noise	327
11.14.2	Signal Averaging	328
11.14.3	Power Spectral Density	328
11.14.4	Units	329
11.15	Frequency Response of a Linear System	330
11.15.1	Example of Calculating the Frequency Response	330
11.15.2	The Decibel	331
11.15.3	Example: Impulse Response	331

11.16	The Frequency Spectrum of Noise	332
11.16.1	Johnson Noise	332
11.16.2	Shot Noise	335
11.16.3	$1/f$ Noise	335
11.17	Testing Data for Chaotic Behavior	335
11.17.1	Embedding	335
11.17.2	Surrogate Data	336
11.18	Stochastic Resonance	337
11.18.1	Threshold Detection	337
11.18.2	Feynman's Ratchet	337
	Symbols Used	338
	Problems	339
	References	343
12	Images	345
12.1	The Convolution Integral and Its Fourier Transform	345
12.1.1	One Dimension	345
12.1.2	Two Dimensions	346
12.2	The Relationship Between the Object and the Image	347
12.2.1	Point Spread Function	347
12.2.2	Optical, Modulation, and Phase Transfer Functions	348
12.2.3	Line and Edge Spread Functions	349
12.3	Spatial Frequencies in an Image	349
12.3.1	Summary	351
12.4	Two-Dimensional Image Reconstruction from Projections by Fourier Transform	351
12.5	Reconstruction from Projections by Filtered Back Projection	352
12.6	An Example of Filtered Back Projection	355
	Symbols Used	358
	Problems	358
	References	362
13	Sound and Ultrasound	363
13.1	The Wave Equation	363
13.1.1	Plane Waves in an Elastic Rod	363
13.1.2	Plane Waves in a Fluid	364
13.1.3	Shear Waves	365
13.2	Properties of the Wave Equation	365
13.3	Acoustic Impedance	366
13.3.1	Relationships Between Pressure, Displacement and Velocity in a Plane Wave	366
13.3.2	Reflection and Transmission of Sound at a Boundary	367
13.4	Comparing Intensities: Decibels	368
13.4.1	The Decibel	368
13.4.2	Measuring Hearing Response	368
13.5	The Ear and Hearing	369
13.6	Attenuation	370
13.7	Diagnostic Uses of Ultrasound	371
13.7.1	Ultrasound Transducers	371
13.7.2	Pulse Echo Imaging	373
13.7.3	The Doppler Effect	374
13.7.4	Elastography	375
13.7.5	Safety	375
13.8	Therapeutic Uses of Ultrasound	375
	Symbols Used	376
	Problems	376
	References	379

14 Atoms and Light	381
14.1 The Nature of Light: Waves and Photons	381
14.2 Electron Waves and Particles: The Electron Microscope	383
14.3 Atomic Energy Levels and Atomic Spectra	383
14.4 Molecular Energy Levels	384
14.5 Scattering and Absorption of Radiation; Cross Section	387
14.6 The Diffusion Approximation to Photon Transport	389
14.6.1 Diffusion Approximation	389
14.6.2 Continuous Measurements	390
14.6.3 Pulsed Measurements	391
14.6.4 Refinements to the Model	391
14.7 Biological Applications of Infrared Scattering	392
14.7.1 Near Infrared (NIR)	392
14.7.2 Optical Coherence Tomography (OCT)	392
14.7.3 Raman Spectroscopy	393
14.7.4 Far Infrared or Terahertz Radiation	394
14.8 Thermal Radiation	394
14.9 Infrared Radiation from the Body	398
14.9.1 Atherosclerotic Coronary Heart Disease	399
14.9.2 Photodynamic Therapy	399
14.10 Blue and Ultraviolet Radiation	400
14.10.1 Treatment of Neonatal Jaundice	400
14.10.2 The Ultraviolet Spectrum	400
14.10.3 Response of the Skin to Ultraviolet Light	401
14.10.4 Ultraviolet Light Causes Skin Cancer	402
14.10.5 Protection From Ultraviolet Light	403
14.10.6 Ultraviolet Light Damages the Eye	403
14.10.7 Ultraviolet Light Therapy	403
14.11 Heating Tissue with Light	404
14.12 Radiometry and Photometry	405
14.12.1 Radiometric Definitions	407
14.12.1.1 Radiant Energy and Power	407
14.12.1.2 Point Source: Radiant Intensity	407
14.12.1.3 Extended Source: Radiance	407
14.12.1.4 Energy Striking a Surface: Irradiance	408
14.12.1.5 Plane-Wave Relationships	409
14.12.1.6 Isotropic Radiation: Lambert's Law	409
14.12.1.7 The Spectrum	409
14.12.2 Photometric Definitions	409
14.12.3 Actinometric Definitions	410
14.13 The Eye	410
14.14 Quantum Effects in Dark-Adapted Vision	413
14.15 Color Vision	415
Symbols Used	415
Problems	417
References	421
15 Interaction of Photons and Charged Particles with Matter	425
15.1 Atomic Energy Levels and X-ray Absorption	425
15.2 Photon Interactions	426
15.2.1 Photoelectric Effect	426
15.2.2 Compton and Incoherent Scattering	427
15.2.3 Coherent Scattering	427

15.2.4	Inelastic Scattering	427
15.2.5	Pair Production	428
15.2.6	Energy Dependence	428
15.3	The Photoelectric Effect	428
15.4	Compton Scattering	428
15.4.1	Kinematics	428
15.4.2	Cross Section: Klein–Nishina Formula	430
15.4.3	Incoherent Scattering	431
15.4.4	Energy Transferred to the Electron	431
15.5	Coherent Scattering	431
15.6	Pair Production	432
15.7	The Photon Attenuation Coefficient	432
15.8	Compounds and Mixtures	433
15.9	Deexcitation of Atoms	434
15.10	Energy Transfer from Photons to Electrons	436
15.11	Charged-Particle Stopping Power	438
15.11.1	Interaction with Target Electrons	442
15.11.2	Scattering from the Nucleus	445
15.11.3	Stopping of Electrons	446
15.11.4	Compounds	446
15.12	Linear Energy Transfer and Restricted Collision Stopping Power	447
15.13	Range, Straggling, and Radiation Yield	447
15.14	Track Structure	448
15.15	Energy Transferred and Energy Imparted; Kerma and Absorbed Dose	450
15.15.1	An Example	450
15.15.2	Energy Transferred and Kerma	451
15.15.3	Energy Imparted and Absorbed Dose	452
15.15.4	Net Energy Transferred, Collision Kerma and Radiative Kerma	452
15.16	Charged-Particle Equilibrium	452
15.16.1	Radiation Equilibrium	452
15.16.2	Charged-Particle Equilibrium	453
15.17	Buildup	454
	Symbols Used	455
	Problems	456
	References	459
16	Medical Uses of X-Rays	461
16.1	Production of X-Rays	461
16.1.1	Characteristic X-Rays	461
16.1.2	Bremsstrahlung	462
16.2	Quantities to Describe Radiation Interactions	463
16.2.1	Radiation Chemical Yield	463
16.2.2	Mean Energy per Ion Pair	463
16.2.3	Exposure	464
16.3	Detectors	464
16.3.1	Film and Screens	465
16.3.2	Scintillation Detectors	466
16.3.3	Gas Detectors	468
16.3.4	Semiconductor Detectors	469
16.3.5	Thermoluminescent Dosimeters	469
16.3.6	Chemical Dosimetry	469
16.3.7	Digital Detectors	470

16.4	The Diagnostic Radiograph	470
16.4.1	X-Ray Tube and Filter	470
16.4.2	Collimation	471
16.4.3	Attenuation in the Patient: Contrast Material	471
16.4.4	Antiscatter Grid	473
16.4.5	Detector	474
16.5	Image Quality	474
16.6	Angiography and Digital Subtraction Angiography	476
16.7	Mammography	477
16.8	Computed Tomography	477
16.9	Biological Effects of Radiation	480
16.9.1	Cell-Culture Experiments	480
16.9.2	Chromosome Damage	481
16.9.3	The Linear-Quadratic Model	482
16.9.4	The Bystander Effect	483
16.9.5	Tissue Irradiation	483
16.9.6	A Model for Tumor Eradication	485
16.10	Radiation Therapy	485
16.10.1	Classical Radiation Therapy	486
16.10.2	Modern X-Ray Therapy	487
16.10.3	Charged Particles and Neutrons	488
16.11	Dose Measurement	489
16.12	The Risk of Radiation	490
16.12.1	Equivalent and Effective Dose	490
16.12.1.1	Equivalent Dose	490
16.12.1.2	Detriment and Effective Dose	491
16.12.2	Comparison With Natural Background	491
16.12.3	Calculating Risk	493
16.12.3.1	The Linear No-Threshold Model and Collective Dose	493
16.12.3.2	Other Models	494
16.12.4	Radon	495
	Symbols Used	496
	Problems	496
	References	500
17	Nuclear Physics and Nuclear Medicine	503
17.1	Nuclear Systematics	503
17.2	Nuclear Decay: Decay Rate and Half-Life	506
17.3	Gamma Decay and Internal Conversion	507
17.4	Atomic Deexcitation	507
17.5	Beta Decay and Electron Capture	507
17.6	Calculating the Absorbed Dose from Radioactive Nuclei within the Body: the MIRD Method	510
17.6.1	Activity and Cumulated Activity	511
17.6.1.1	The General Distribution Problem: Residence Time	512
17.6.1.2	Immediate Uptake with No Biological Excretion	512
17.6.1.3	Immediate Uptake with Exponential Biological Excretion	512
17.6.1.4	Immediate Uptake Moving through Two Compartments	513
17.6.1.5	More Complicated Situations	514
17.6.1.6	Activity per Unit Mass	514
17.6.2	Mean Energy Emitted Per Unit Cumulated Activity	514
17.6.3	Calculation of the Absorbed Fraction	514
17.6.3.1	Nonpenetrating Radiation	514
17.6.3.2	Infinite Source in an Infinite Medium	514
17.6.3.3	Point Source of Monoenergetic Photons in Empty Space	514

17.6.3.4	Point Source of Monoenergetic Photons in an Infinite Isotropic Absorber	515
17.6.3.5	More Complicated Cases—the MIRD Tables	515
17.6.4	Sample Dose Calculation	517
17.7	Radiopharmaceuticals and Tracers	517
17.7.1	Physical Properties	517
17.7.2	Biological Properties	519
17.8	Detectors; The Gamma Camera	520
17.9	Single-Photon Emission Computed Tomography	521
17.10	Positron Emission Tomography	523
17.11	Brachytherapy and Internal Radiotherapy	523
17.12	Radon	524
	Symbols Used	526
	Problems	527
	References	532
18	Magnetic Resonance Imaging	535
18.1	Magnetic Moments in an External Magnetic Field	535
18.2	The Source of the Magnetic Moment	536
18.3	The Magnetization	537
18.4	Behavior of the Magnetization Vector	538
18.5	A Rotating Coordinate System	539
18.5.1	Transforming to the Rotating Coordinate System	539
18.5.2	An Additional Oscillating Field	540
18.5.3	Nutation	541
18.5.4	π and $\pi/2$ Pulses	541
18.6	Relaxation Times	542
18.7	Detecting the Magnetic Resonance Signal	544
18.8	Some Useful Pulse Sequences	545
18.8.1	Free-Induction-Decay (FID) Sequence	546
18.8.2	Inversion-Recovery (IR) Sequence	546
18.8.3	Spin-Echo (SE) Sequence	546
18.8.4	Carr–Purcell (CP) Sequence	547
18.8.5	Carr–Purcell–Meiboom–Gill (CPMG) Sequence	547
18.9	Imaging	548
18.9.1	Slice Selection	548
18.9.2	Readout in the Direction	550
18.9.3	Projection Reconstruction	551
18.9.4	Phase Encoding	551
18.9.5	Other Pulse Sequences	553
18.9.6	Image Contrast and the Pulse Parameters	554
18.9.7	Safety	555
18.10	Chemical Shift	555
18.11	Flow Effects	555
18.12	Functional MRI	557
18.13	Diffusion and Diffusion Tensor MRI	557
18.14	Hyperpolarized MRI of the Lung	558
	Symbols Used	559
	Problems	559
	References	564
A	Appendix A	567
	Plane and Solid Angles	567
A.1	Plane Angles	567
A.2	Solid Angles	567

B	Appendix B	
	Vectors; Displacement, Velocity, and Acceleration	569
B.1	Vectors and Vector Addition	569
B.2	Components of Vectors	570
B.3	Position, Velocity, and Acceleration	570
C	Appendix C	
	Properties of Exponents and Logarithms	573
D	Appendix D	
	Taylor's Series	575
E	Appendix E	
	Some Integrals of Sines and Cosines	579
F	Appendix F	
	Linear Differential Equations with Constant Coefficients	581
F.1	First-Order Equation	582
F.2	Second-Order Equation	582
G	Appendix G	
	The Mean and Standard Deviation	585
H	Appendix H	
	The Binomial Probability Distribution	587
I	Appendix I	
	The Gaussian Probability Distribution	591
J	Appendix J	
	The Poisson Distribution	595
K	Appendix K	
	Integrals Involving e^{-ax^2}	599
L	Appendix L	
	Spherical and Cylindrical Coordinates	601
M	Appendix M	
	Joint Probability Distributions	605
M.1	Discrete Variables	605
M.2	Continuous Variables	605
N	Appendix N	
	Partial Derivatives	607
O	Appendix O	
	Some Fundamental Constants and Conversion Factors	609
	Index	611

Intermediate Physics for Medicine and Biology

Hobbie, R.K.; Roth, B.J.

2015, XX, 629 p. 667 illus., 18 illus. in color., Hardcover

ISBN: 978-3-319-12681-4