

Contents

Preface	xiii
Chapter 1 Fundamental Concepts of Radiometry	1
1.1 Electromagnetic Radiation	1
1.2 Terminology Conventions	3
1.3 Wavelength Notations and Solid Angle	4
1.4 Fundamental Definitions	7
1.5 Lambertian Radiators and Lambert's Cosine Law	13
1.6 Radiance, Irradiance, Intensity, and Flux Relationships	15
1.7 Connection with Electromagnetic Theory	20
1.8 Polarization	22
1.9 Photon Flux	25
Example Problem 1.1	28
Example Problem 1.2	30
References	32
Chapter 2 Fundamental Concepts of Photometry	33
2.1 Light	33
2.2 Photometric Definitions	37
2.2.1 Radiation Luminous Efficacy, K_r , and the V-lambda Function	41
2.2.2 Lighting System Luminous Efficacy, K_s	43
2.3 Luminance and Brightness	45
2.4 Luminance and Vision	47
2.5 Disability Glare	50
2.6 Discomfort Glare	52
2.7 Illumination	54
2.7.1 Illuminance Selection	55
Example Problem 2.1	57
Example Problem 2.2	59

Example Problem 2.3	61
References	61
Chapter 3 Blackbodies and Other Sources	63
3.1 Blackbody Radiation	63
3.2 Planck's Law	64
3.3 Wien Displacement Law	68
3.4 Luminous Efficacy of Blackbody Radiation	69
3.5 Color and Distribution Temperatures	71
3.6 Emission into an Imperfect Vacuum	72
3.7 Radiation Exchange	73
3.8 Experimental Approximation of a Blackbody	73
3.9 Other Real Sources	74
Example Problem 3.1	82
Example Problem 3.2	82
Example Problem 3.3	83
Example Problem 3.4	83
Example Problem 3.5	84
References	84
Chapter 4 Source/Receiver Flux Transfer Calculations	87
4.1 Introduction	87
4.2 Geometry and Definitions	87
4.2.1 Case 1	90
4.2.2 Case 2	91
4.2.3 Case 3	92
4.2.4 Case 4	93
4.2.5 Case 5	95
4.2.6 Case 6	96
4.2.7 Case 7	98
4.2.8 Monte Carlo Method	99
4.3 Configuration Factor	100
4.4 Net Exchange of Radiation	102
4.5 Summary	103
Example Problem 4.1	104
References	105
Chapter 5 The Invariance of Radiance and the Limits of Optical Concentration	107
5.1 Introduction	107
5.2 Radiance is a Field Quantity	107
5.3 Pencils of Rays	108
5.4 Elementary Beam of Radiation	109
5.5 Radiance Invariance	111

5.6	Radiance Invariance at an Interface	112
5.7	Radiance Through a Lens	114
5.8	Radiance in Absorbing and Scattering Media	115
5.9	Concentrating Radiance Meter	116
5.10	The Limits of Optical Concentration	120
	Example Problem 5.1	123
	Example Problem 5.2	124
	References	125
Chapter 6 Optical Properties of Materials		127
6.1	Introduction	127
6.2	Terminology	128
6.3	Surface and Interface Optical Properties	130
6.3.1	Conductor Optical Properties	130
6.3.2	Nonconductor Optical Properties	131
6.3.3	Surface Emission Properties	132
6.3.4	Angular Dependence of Dielectric Optical Properties	136
6.3.5	Rough Surfaces	141
6.4	Bulk Medium Optical Properties	142
6.5	Properties of Plane Parallel Plates	148
6.5.1	Nonscattering Media	148
6.5.2	Scattering Media	154
6.6	Angular Dependence	156
6.7	Broadband Angle Properties	160
6.7.1	Transmittance and Reflectance Equations	160
6.7.2	Specular and Diffuse Optical Properties	162
6.8	Spectral Dependence	164
6.9	Broadband Spectral Properties	165
6.10	Spectral Selectivity	167
	Example Problem 6.1	174
	Example Problem 6.2	175
	References	175
Chapter 7 The Detection of Radiation		179
7.1	Introduction	179
7.2	Basic Concepts	180
7.3	Classification of Detectors	187
7.3.1	Thermal Detectors	187
7.3.2	Photemissive Detectors	191
7.3.3	Semiconductor Devices	197
7.3.4	Multi-element Detectors, Charge Transfer Devices, and Imagers	205
7.4	Detector Noise	209

7.5	Signal Modulation and Radiation Chopping	211
7.6	Characterization of Detector Performance	215
7.6.1	Responsivity, R	216
7.6.2	Quantum Efficiency, η	216
7.6.3	Noise Equivalent Power, NEP	217
7.6.4	Detectivity, D	218
7.6.5	Photon Noise-Limited Performance	219
7.7	Flux Conditioning Prior to the Detector	220
7.7.1	Cosine Response Correction	221
7.7.2	Photopic Correction	224
7.7.3	Spectral Filtering	224
7.8	Signal Conditioning After the Detector	227
7.9	Detector Calibration	227
7.10	Example Detectors and Their Characteristics	229
	Example Problem 7.1	234
	References	237
	Appendix 7A	240
	Chapter 8 Optical Systems	243
8.1	Introduction	243
8.2	Optical Axis	244
8.3	Idealized (Thin) Lens Theory	245
8.4	Radiance and Irradiance of Images	250
8.5	Vignetting	253
8.6	Aberrations	254
8.6.1	Spherical Aberration	254
8.6.2	Chromatic Aberration	257
8.6.3	Distortion	258
8.6.4	Coma	258
8.6.5	Astigmatism	259
8.6.6	Field Curvature	261
8.6.7	Correcting Aberrations	261
8.6.8	The Diffraction Limit	261
8.7	Image Quality	263
8.8	Flux Distribution	265
8.9	Nonimaging Optical Systems	266
8.10	Throughput	269
8.11	Integrating Spheres	271
8.11.1	Cosine Correction	274
8.11.2	Transmissometers and Reflectometers	274
8.12	Monochromators	280
8.12.1	Spectral Filters	280

8.12.2 Scanning Monochromators	287
8.13 Windows	293
8.14 Sources	294
8.15 Goniometers	295
8.16 Transmissometers/Reflectometers	296
8.17 Scattering Meters, Nephelometers, Turbidimeters, and Haze Meters	296
Example Problem 8.1	297
References	300
 Chapter 9 Radiometers and Photometers	303
9.1 Introduction	303
9.2 General Design Factors	305
9.3 Broadband Irradiance and Radiance Meters	306
9.4 Restricted Spectral Band Irradiance Meters for the Ultraviolet Through the Infrared	310
9.5 Illuminance and Luminance Meters	311
9.6 Spectroradiometers	312
9.7 Calibration of Radiometers and Photometers	314
9.7.1 Transfer Standards	316
9.7.2 Broadband Irradiance Standard Sources	318
9.7.3 Standard Sources for Spectral Irradiance and Spectral Radiance	319
9.7.4 Absolute Radiometry	322
9.7.5 Standard Illuminance and Luminance Sources	326
9.7.6 Radiometer/Photometer Calibration Using Standard Sources	327
9.7.7 Spectroradiometer Calibration	328
9.7.8 National Standards Laboratories	329
Example Problem 9.1	329
Example Problem 9.2	330
References	330
 Chapter 10 Metric Primer and Additional Radiometric and Photometric Quantities and Units	333
10.1 Introduction	333
10.2 The SI System of Units	334
10.2.1 Basic Metric Principles	334
10.2.2 Metric Units for Radiometry and Photometry	336
10.3 The I-P System of Units	336
10.4 Photon Flux Units	336
10.5 Other Quantities and Units	338
References	340

Chapter 11 Basic Concepts of Color Science	343
11.1 Introduction	343
11.2 Basic Concepts and Definitions	344
11.3 Systems of Color Specification	349
11.3.1 Munsell Color System	349
11.3.2 CIE 1976 ($L^*a^*b^*$) Color Space	352
11.3.3 Tristimulus Colorimetry	352
11.4 CIE 1931 Color System	354
11.5 CIE 1964 Supplementary Observer Color System	359
11.6 CIE 1976 Uniform Color Space	359
11.7 Color Temperature	364
11.8 Standard Illuminants and Reflection Colorimetry	366
11.8.1 Blackbody Illuminants	367
11.8.2 Daylight Illuminants	369
11.8.3 Reflection Colorimetry	371
11.9 Color Rendering Index	372
References	375
Appendix Correspondence Between Finite Elements and the Calculus	377
A.1 Introduction	377
A.2 Definition of the Derivative	378
A.3 Definition of the Integral	380
A.4 Integrals as Sums	382
A.5 Sums Over Solid Angles	383
References	387
About the Author	389
Index	391