

Volume II

## Chapter 2

## Radiometric and Photometric Concepts

2.0	<u>Introduction</u>	1
2.1	<u>Radiant Flux</u>	2
	Basic Photoelectric Effects	3
	Operational Definition of Radiant Flux	5
2.2	<u>The Meaning of 'Radiant Flux'</u>	8
2.3	<u>Fundamental Geometric Properties of Radiant Flux</u>	10
2.4	<u>Irradiance and Radiant Emittance</u>	14
	Definition of Irradiance	14
	The Meaning of 'Irradiance'	16
	Terrestrial Coordinate Systems	19
	Representation of Irradiance in Terrestrial Frames	24
	The Cosine Law for Irradiance	26
	Radiant Emittance	28
2.5	<u>Radiance</u>	30
	Radiance Distributions	34
	Irradiance from Radiance	35
	Radiance from Irradiance	41
	Field Radiance vs Surface Radiance	44
2.6	<u>An Invariance Property of Radiance</u>	46
	The Radiance-Invariance Law	46
	The Operational Meaning of Surface Radiance	49
	The $n^2$ -Law for Radiance	51
2.7	<u>Scalar Irradiance, Radiant Energy, and Related Concepts</u>	54
	Radiant Density	54
	Scalar Irradiance	55
	Spherical Irradiance	56
	Hemispherical Irradiance	58
	Radiant Energy over Space	60
	Radiant Energy over Time	61
	Scalar Radiant Emittance	61
2.8	<u>Vector Irradiance</u>	62
	A Mechanical Analogy	62
	General Definition of Vector Irradiance	65
	The General Cosine Law for Irradiance	66

2.9	<u>Radiant Intensity</u>	70
	Operational Definition of Empirical Radiant Intensity	70
	Field Intensity vs Surface Intensity	72
	Theoretical Radiant Intensity	73
	Radiant Intensity and Point Sources	74
	Cosine Law for Radiant Intensity	77
	Generalized Cosine Law for Radiant Intensity	80
2.10	<u>Polarized Radiance</u>	83
	Operational Definition of Polarized Radiance	85
	The Standard Stokes and Standard Observable Vectors	88
	Analytic Link Between S and N	90
	Standard and Local Reference Frames	91
	Radiant Flux Content of Polarized Radiance	94
2.11	<u>Examples Illustrating the Radiometric Concepts</u>	95
	1. Radiance of the Sun and Moon	96
	2. Radiant Intensity of the Sun and Moon	98
	3. Radiant Flux Incident on Portions of the Earth	101
	4. Irradiance Distance-Law for Spheres	103
	5. Irradiance Distance-Law for Circular Disks; Criterion for a Point Source	105
	6. Irradiance Distance-Law for General Surfaces	106
	7. Irradiance via Line Integrals	109
	8. Solid Angle Subtense of Surfaces	112
	9. Irradiance via Surface Integrals	115
	10. Radiant Flux Calculations	117
	11. Intensity Area-Law for General Surfaces	119
	12. On the Possibility of Inverse nth Power Irradiance Laws	120
	13. Irradiance from Elliptical Radiance Distributions	131
	14. Irradiance from Polynomial Radiance Distributions	138
	15. On the Formal Equivalence of Radiance and Irradiance Distributions	143
2.12	<u>Transition from Radiometry to Photometry</u>	151
	The Individual Luminosity Functions	152
	The Standard Luminosity Functions	157
	Photometric Bedrock: the Lumen	161
	Luminance Distributions	163
	Transition to Geometrical Photometry	165
	General Properties of the Radiometric-Photometric Transition Operator	169
	The Mathematical Basis for Geometrical Photometry	169
	Summary and Examples (Tables of Radiometric and Photometric Concepts)	170
2.13	<u>Generalized Photometries</u>	183
	Linear Photometries	184
	Nonlinear Photometries	185
2.14	<u>Bibliographic Notes for Chapter 2</u>	187

## Chapter 3

## The Interaction Principle

3.0	<u>Introduction</u>	188
	The Physical Basis of the Linearity of the Interaction Principle	189
	Plan of the Chapter	193
3.1	<u>A Preliminary Example</u>	194
	Empirical Reflectances and Transmittances for Surfaces	194
	The Problem	196
	The Present Instance of the Interaction Principle	197
	Solution of the Problem	198
	Discussion of Solution	199
	Related Problems and Their Solutions	200
	An Alternate Form of the Principle	201
	The Natural Mode of Solution	203
3.2	<u>The Interaction Principle</u>	205
	Discussion of the Interaction Principle	206
	The Place of the Interaction Principle in Radiative Transfer Theory	208
	The Levels of Interpretation of the Interaction Principle	208
3.3	<u>Reflectance and Transmittance Operators for Surfaces</u>	210
	Geometrical Conventions	210
	The Empirical Reflectances and Transmittances	212
	The Theoretical Reflectances and Transmittances	213
	Variations of the Basic Theme	215
3.4	<u>Applications to Plane Surfaces</u>	217
	Example 1: Irradiances on Two Infinite Parallel Planes	217
	Example 2: Irradiances on Two Infinite Parallel Planes, Reexamined. A First Synthesis of the Interaction Method	220
	Example 3: Irradiances on Finitely Many Infinite Parallel Planes	223
	Example 4: Irradiances on Infinitely Many Infinite Parallel Planes	227
	Example 5: The Algebra of Reflectance and Transmittance Operators for Planes. Radiometric Norm. Iterated Operators. Operator Algebras and Radiative Transfer.	230
	Example 6: Radiances of Infinite Parallel Planes	244
	Example 7: Terminable and Non Terminable Inter- reflection Calculations. A Terminable Calcula- tion. Truncation Error Estimates. Quantum- terminable Calculations.	248
	Example 8: Two Interacting Finite Plane Surfaces	254

3.5	<u>Applications to Curved Surfaces</u>	258
	Example 1: Open Concave Surfaces	258
	Example 2: Closed Concave Surfaces; the Integrating Sphere	262
	Example 3: Open and Closed Convex Surfaces	266
	Example 4: General Two-Sided Surfaces	267
	Example 5: General One-Sided Surfaces	271
3.6	<u>Reflectance and Transmittance Operators for Plane-Parallel Media</u>	279
	Geometrical Conventions	279
	The Empirical Reflectances and Transmittances	280
	The Theoretical Reflectances and Transmittances	282
	Variations of the Basic Theme	284
3.7	<u>Applications to Plane-Parallel Media</u>	285
	Example 1: Irradiances on Plane-Parallel Media	286
	Example 2: Radiances in Plane-Parallel Media	290
	Example 3: The Classical Principles of Invariance	294
	Example 4: The Invariant Imbedding Relation	297
	Example 5: Semigroup Properties of Transmitted and Reflected Radiant Flux	300
	Example 6: The Generalized Invariant Imbedding Relation	301
	Example 7: Group-Theoretic Structure of Natural Light Fields. Group Theory, Radiative Transfer and Quantum Theory.	307
3.8	<u>Interaction Operators for General Spaces</u>	314
	Geometrical Conventions	314
	The Empirical Scattering Functions	317
	The Theoretical Scattering Functions	318
	Variations of the Basic Theme	322
3.9	<u>Applications to General Spaces</u>	322
	Example 1: Principles of Invariance on Spherical, Cylindrical, Toroidal Media	325
	Example 2: Invariant Imbedding Relation for One-Parameter Media	327
	Example 3: One-Parameter Media with Internal Sources	330
	Example 4: Principles of Invariance for General Media	336
	Example 5: Invariant Imbedding Relation in General Media	339
	Example 6: Reflecting Boundaries and Interfaces	340
	Example 7: The Unified Atmosphere-Hydrosphere Problem	343
	Example 8: Several Interacting Separate Media	344
3.10	<u>Derivation of the Beam Transmittance Function</u>	344
3.11	<u>Derivation of the Volume Attenuation Function</u>	349

3.12	<u>Derivation of Path Radiance and Path Function</u>	351
	The Path Radiance	351
	The Path Function	352
	The Connection Between Path Function and Path Radiance	354
3.13	<u>Derivation of Apparent-Radiance Equation</u>	361
3.14	<u>Derivation of the Volume Scattering Function</u>	364
	Regularity Properties of $\sigma$	366
	The Integral Representation of the Path Function	367
3.15	<u>The Equation of Transfer for Radiance</u>	368
	Steady State Equation of Transfer	370
	Time Dependent and Polarized Equations of Transfer	371
3.16	<u>On the Integral Structure of the Interaction Operators</u>	372
	The Mathematical Prerequisites	373
	Interaction Operators for Surfaces	377
	Interaction Operators for General Media	378
	Interaction Measures and Kernels	380
3.17	<u>Further Examples of the Interaction Method</u>	383
	Example 1: The Path Function Operator	383
	Example 2: The Path Radiance Operator	384
	Example 3: The Volume Transpectral Scattering Operator	386
	Miscellaneous Examples	387
3.18	<u>Summary of the Interaction Method</u>	388
	Summary of the Interaction Method	388
	Remarks on the Stages of the Interaction Method	389
	The Interaction Method and Quantum Theory	390
	The Interaction Principle as a Means and as an End, Conclusion	391
3.19	<u>Bibliographic Notes for Chapter 3</u>	392