

CONTENTS

CHAPTER 1 PHYSICAL DATA

1.1	Basic Radiometric Quantities and Units	1
1.2	Sources of Radiant Energy	1
1.2.1	The Sun and Daylight	4
1.2.2	Thermal Radiators	11
1.2.3	Electric Discharge Lamps	19
1.2.4	Electroluminescent Sources	23
1.2.5	Light-Emitting Diodes	25
1.2.6	Lasers	25
1.2.7	Sources of Ultraviolet Radiant Energy	27
1.2.8	Some Photometric and Colorimetric Characteristics of Sources of Radiant Energy	27
1.3	Optical Filters	30
1.3.1	Absorption Filters	30
1.3.2	Glass Filters	34
1.3.3	Gelatin Filters	35
1.3.4	Liquid Filters	35
1.3.5	Absorption Filters for Special Applications	35
1.3.6	Miscellaneous Absorption Filters	40
1.3.7	Interference Filters	40
1.3.8	Interference-Filter Wedges	46
1.3.9	Beamsplitters	48
1.3.10	Sheet Polarizers	49
1.3.11	Miscellaneous Optical Filters	51
1.4	Reflecting Materials	51
1.4.1	Front-Surface Mirrors	55
1.4.2	White Reflectance Standards	55
1.4.3	Colored Reflectance Standards	58
1.4.4	Black Surfaces	60
1.4.5	Building Materials	60
1.4.6	Natural Objects	60

1.5	Monochromators	63
1.5.1	Basic Designs of Monochromators	63
1.5.2	Resolving Power and Transmitted Radiant Flux	66
1.5.3	Slit-Width Correction	69
1.5.4	Polarization	70
1.5.5	Wavelength Calibration	71
1.5.6	Stray Light	72
1.6	Physical Detectors of Radiant Energy	72
1.6.1	Thermal Detectors	73
1.6.2	Photon Detectors	76

CHAPTER 2 THE EYE

2.1	Preamble	83
2.2	The Structure of the Human Eye	83
2.2.1	Cornea	84
2.2.2	Lens	84
2.2.3	Aqueous Humor and Vitreous Body	84
2.2.4	The Fine-Structure of the Retina	85
2.2.5	Main Topographical Features of the Retina	88
2.2.6	The Fovea	90
2.2.7	The Photoreceptors	90
2.3	Specification of the External Stimulus	93
2.3.1	Position in External Field	93
2.3.2	Radiometric Specification	93
2.3.3	Photometric Specification	95
2.4	Factors in the Eye That Control the Internal Stimulus	95
2.4.1	Image Formation by the Theoretical Eye	98
2.4.2	Eye Axes and Eye Angles	100
2.4.3	Chromatic Aberration of the Eye	101
2.4.4	The Troland Values of Retinal Illuminance	102
2.4.5	Pupil Size	105
2.4.6	Light Losses in the Eye	107
2.4.7	Fluorescent Light in the Eye	116

CHAPTER 3 COLORIMETRY

3.1	Preamble	117
3.2	Basic Colorimetric Concepts	117
3.2.1	Trichromatic Generalization	117
3.2.2	Tristimulus Space	119
3.2.3	Basic Colorimetric Equations	121
3.2.4	Imaginary Color Stimuli	127
3.2.5	Colorimetric Transformations	129

3.3	The CIE Colorimetric System	130
3.3.1	The CIE 1931 Standard Colorimetric Observer	131
3.3.2	The CIE 1964 Supplementary Standard Colorimetric Observer	132
3.3.3	Development of the Two CIE Standard Observers	133
3.3.4	CIE Standard Illuminants	143
3.3.5	CIE Standard Sources	146
3.3.6	Standard of Reflectance Factor	155
3.3.7	Standard Illuminating and Viewing Conditions	155
3.3.8	Calculation of CIE Tristimulus Values and Chromaticity Coordinates	156
3.3.9	CIE Uniform Color Spaces and Color-Difference Formulae	164
3.3.10	CIE Metamerism Index for Change in Illuminant	169
3.3.11	CIE Color-Rendering Index	173
3.4	Dominant Wavelength, Excitation Purity, and Colorimetric Purity	175
3.5	Complementary Color Stimuli	176
3.6	Maximum Attainable Luminous Efficiency of Color Stimuli of Different Chromaticity	177
3.7	Optimal Object-Color Stimuli	179
3.8	Metameric Color Stimuli	183
3.8.1	Definition of Metamerism	184
3.8.2	Methods of Generating Metamers	185
3.8.3	Intersections of Spectral Reflectance Curves of Metamers	194
3.8.4	Counting Metamers	196
3.8.5	Boundaries of Mismatches of Metamers	200
3.8.6	Application of Linear Programming to Miscellaneous Colorimetric Problems	212
3.9	Colorant Formulation	221
3.10	Specification of Color Tolerances	222
3.11	Distribution Temperature, Color Temperature, and Correlated Color Temperature	224
3.12	Colorimetric Instrumentation	228
3.12.1	Spectroradiometers	229
3.12.2	Spectrophotometers	232
3.12.3	Spectrophotometry of Fluorescent Materials	235
3.12.4	Propagation of Random Spectrophotometric Errors	240
3.12.5	Tristimulus-Filter Colorimeters	243

CHAPTER 4 PHOTOMETRY

4.1	Basic Photometric Quantities and Units	249
4.2	The Photometric Principle	249

4.3	The Standard Photometric System	253
4.3.1	Historical Note	253
4.3.2	Standard Photometric Observers	256
4.3.3	Photometric Methods	259
4.3.4	Measurement of Total Luminous Flux	263
4.3.5	Measurement of Luminous Intensity and Illuminance	265
4.3.6	Measurement of Luminance	270
4.4	Calculation of Illuminance Produced by Lambert Sources of Different Shapes	277
CHAPTER 5 VISUAL EQUIVALENCE AND VISUAL MATCHING		
5.1	Preamble	278
5.2	Classification of Matching Procedures	278
5.2.1	Visual Equivalence and Visual Match by Strict Substitution	279
5.2.2	Asymmetric Comparison and Matching; Quasi-symmetric Matching	281
5.2.3	Limited Groups of Asymmetric Matching Procedures	283
5.2.4	Matching Criteria	285
5.2.5	Some Particular Matching or Equivalence Procedures	288
5.3	Maxwell's Method of Color Matching	293
5.3.1	Historical Note	293
5.3.2	Basis of Maxwellian Trichromacy	294
5.3.3	Maxwell Trichromacy and Full Trichromacy in Quasi-Symmetric Matching	298
5.3.4	Maxwell's Method in Nontrichromatic Matching	300
5.3.5	Maxwellian Matching as Correlation of Stimulus Spaces	302
5.3.6	Maxwellian Matching in the Weaker Sense	304
5.4	Precision of Color Matching for Normal Trichromats	306
5.4.1	MacAdam Ellipses	306
5.4.2	Brown-MacAdam Ellipsoids	313
5.4.3	Wysecki-Fielder Ellipsoids	319
5.4.4	Repeatability of Color-Matching Ellipsoids for the Same Observer	320
5.4.5	Intercomparison of Color-Matching Ellipses for Different Observers	323
5.4.6	Propagation of Random Errors in Colorimetric Transformations	328
5.5	Color-Matching Functions of Normal Trichromats	330
5.5.1	Two-Degree Data of Guild and Wright	330
5.5.2	Judd Modification	330
5.5.3	Stiles Two-Degree Pilot Data	333
5.5.4	Stiles-Burch Ten-Degree Data	333
5.5.5	ETL Ten-Degree Data	343
5.5.6	Variations of Color-Matching Functions of Different Normal Trichromats	346

5.6	Factors Modifying Color Matching	347
5.6.1	Filter Pigments in the Eye	347
5.6.2	Rod Participation	354
5.6.3	Location of Visual Field	372
5.6.4	Size of Visual Field	373
5.6.5	High Luminance Level	374
5.6.6	Maxwell Method versus Maximum-Saturation Method	379
5.7	Luminous Efficiency Functions of Normal Trichromats	392
5.7.1	Matching or Equivalence Criteria and Experimental Procedures	392
5.7.2	Experimental Data	394
5.8	Heterochromatic Brightness Matching of Complex Stimuli	410
5.8.1	Luminance of Equally Bright Color Stimuli	411
5.8.2	Additivity Failures	413
5.9	Abney and Bezold-Brücke Effects	420
5.10	Hue Reversals: Brindley Isochromes	424
5.11	Stiles-Crawford Effect	424
5.12	Chromatic Adaptation	429
5.12.1	Asymmetric Matching—Basic Concepts	429
5.12.2	Experimental Procedures and Data	432
5.12.3	A Comparison of Chromatic-Adaptation Transforms	449
5.13	Chromatic-Response Functions	451
5.14	Color-Matching Properties of Color-Defective Observers	458
5.14.1	Normal and Anomalous Trichromats	459
5.14.2	Dichromats	463
5.14.3	Monochromats	471
5.15	Instrumentation for Color-Vision Research	472
5.15.1	Maxwellian View	478
5.15.2	Measurement of Directional Sensitivity and Increment Thresholds	483
5.15.3	The Staircase Methods	484
CHAPTER 6 UNIFORM COLOR SCALES		
6.1	Preamble	486
6.2	Types of Scales and Scaling Methods	488
6.3	Brightness and Lightness Scales	493
6.4	Color Scales of Constant Lightness	500
6.5	Three-Dimensional Color Scales	503

6.5.1	Principles of Construction	503
6.5.2	Color-Difference Formulae	504
6.5.3	White, Whiteness Formulae	506
6.6	Color-Order Systems	506
6.6.1	Munsell Color System	507
6.6.2	DIN Color System	509
6.6.3	Swedish Natural Color System	511
6.6.4	OSA Color System	512
 CHAPTER 7 VISUAL THRESHOLDS		
7.1	Preamble	514
7.2	General Concepts	514
7.2.1	Basic Terms and Definitions	514
7.2.2	Quantum Fluctuations and Visual Stimuli	516
7.3	Dark Adaptation and Absolute Thresholds	519
7.3.1	Recovery of Threshold Sensitivity; Dark-Adaptation Curves	519
7.3.2	Threshold Variation Over the Visual Field	521
7.3.3	Threshold Sensitivity of Fully Dark-Adapted Eye	521
7.3.4	Absolute Threshold Values for Different Conditions of Measurement	521
7.4	Chromatic Adaptation and Increment Thresholds	525
7.4.1	Two-Color Threshold Method	525
7.4.2	Basic Formulae	528
7.4.3	Stiles' Mean Data	531
7.4.4	Specific Aspects of π Mechanisms and Later Developments	537
7.5	Rod Saturation	544
7.6	Cone Saturation	547
7.7	Rod and Cone Interactions	549
7.8	Uniform Equivalent Fields	552
7.8.1	Basic Formulae	553
7.9	Spatial and Temporal Factors	554
7.9.1	Distinctness of Border	555
7.9.2	Mach Bands	556
7.9.3	Flicker	557
7.10	Discrimination Thresholds	567
7.10.1	Luminance Differences	567
7.10.2	Wavelength Differences	570
7.10.3	Purity Differences	571

7.10.4	Color-Temperature Differences	574
7.10.5	Chromaticity Differences	575
7.10.6	Color-Difference Matches	576
 CHAPTER 8 THEORIES AND MODELS OF COLOR VISION		
8.1	Preamble	582
8.2	Visual Response Functions and the Spectral Properties of Visual Pigments	586
8.2.1	Principle of Univariance	586
8.2.2	The Visual-Pigment Layer	588
8.2.3	Dartnall's Standard Shape of Visual Pigment-Absorption Coefficient	591
8.2.4	Color-Matching Data and the Spectral Absorption Curves of Visual Pigments	591
8.2.5	Dichromatism and the Fundamental Spectral Sensitivities	604
8.2.6	Color-Matching Data and the Pigment-Bleaching Model	619
8.3	Neural Models	633
8.3.1	Müller and Judd	634
8.3.2	Adams	639
8.3.3	Hurvich and Jameson	642
8.3.4	Guth	646
8.3.5	Ingling	652
8.4	Line Elements of Color Space	654
8.4.1	Basic Concepts	654
8.4.2	Helmholtz	658
8.4.3	Schrödinger	659
8.4.4	Stiles	660
8.4.5	Trabka	672
8.4.6	Vos and Walraven	673
8.4.7	General Construction of Inductive Line Elements	677
 APPENDIX OF EXTENDED TABLES AND ILLUSTRATIONS		
		690
 REFERENCES		
		885
 AUTHOR INDEX		
		925
 SUBJECT INDEX		
		935