

CONTENTS

1	THE PHYSICAL NATURE OF LIGHT	1
1.1	Early Ideas	2
1.2	The Speed of Light	2
1.3	The Origin of Color	5
1.4	Waves	6
1.5	The Wave-Particle Controversy	11
1.6	The Transverse Wave Theory of Light	13
1.7	Electric and Magnetic Fields	14
1.8	The Photon Theory of Light	18
1.9	Light and Energy	20
	In Conclusion	21
	Problems and Exercises	21
2	THE ORIGIN OF COLOR	24
2.1	The Terminology of Illumination	24
	Physical Units	25
	Luminous Units	26
2.2	Continuum Sources	27
	Blackbody Radiation	28
2.3	Bright-Line Sources	31
2.4	Reflectance	35
2.5	Transmission	39
2.6	Absorption	40
2.7	Primary Colors	41
	Additive Primaries	41
	Subtractive Primaries	43
2.8	Application of Color Concepts	45
	Color Television	45
	Color Printing	47
	The Mixing of Pigments	50
	Oils	50

Watercolors	52
Interior Decorating and Fashion Design	52
Stage Lighting	53
In Conclusion	54
Problems and Exercises	55
3 COLORIMETRY – DESCRIBING AND MEASURING COLOR	59
3.1 Newton's Colorimetric System	60
3.2 The CIE System	63
Metamerism	63
The Laws of Color Matching	63
The XYZ System	68
Chromaticity Coordinates	69
Use of the CIE Chromaticity Diagram	71
Dominant Wavelength and Purity	73
The Analysis of Surfaces	75
A Word of Caution	78
3.3 The Munsell Color Notation System	78
3.4 The Ostwald Color System	80
In Conclusion	82
Problems and Exercises	83
4 COLOR VISION	85
4.1 Basic Features of Color Vision	85
Trichromacy	85
Color Constancy	85
Contrast Effects	86
Afterimages	88
Color Blindness	88
Lightness Constancy	88
4.2 Early Theories	89
Newton	89
Young	90
4.3 Theories of the Late Nineteenth Century	91
Hemholtz	91
Hering	94
4.4 Current Theories of Color Vision	96
Details of the Visual System	96
The Zone Theory	99
The Retinex Theory	103
The Importance of Edges	106
Kuffler Units	108
In Conclusion	109
Problems and Exercises	109

5	THE APPEARANCE OF OBJECTS	111
5.1	Reflection from Opaque Surfaces	113
	Metals	113
	Nonmetallic Surfaces	113
5.2	Transparent Colorants	115
	Single Colorant: Effect of Thickness and Concentration	117
	Transparent Colorant Mixtures	121
5.3	Opaque Colorants	123
	The Pigment Particles	124
	The Support	125
	The Outer Surface	126
	Colorant Mixtures	127
5.4	The Use of Color in Painting	129
	Problems and Exercises	132
6	GEOMETRIC OPTICS	133
6.1	Reflection	133
6.2	Plane Mirrors	134
6.3	Curved Mirrors	137
6.4	Refraction	143
6.5	Refraction by Lenses	154
6.6	Chromatic Aberration	156
6.7	Lens Equations	157
	In Conclusion	161
	Problems and Exercises	162
7	APPLIED GEOMETRICAL OPTICS	163
7.1	The Reduced Eye	163
7.2	Adaptation	167
7.3	Defects of Vision	168
	Chromatic Aberration	170
	Spherical Aberration	171
7.4	The Camera	171
	Telephoto Lenses	174
	Sensitivity to Light	175
	Intensity of the Camera Image; f -Numbers	176
	Exposure Times; Film Speed	180
	Depth of Field	182
	Chromatic Aberration	183
	Spherical Aberration	184
7.5	Other Optical Devices	185
	The Magnifier	185
	The Compound Microscope	188

X CONTENTS

Telescopes	190
The Reflecting Telescope	194
The Slide Projector	196
Problems and Exercises	198
8 WAVE OPTICS	199
8.1 Young's Two Slit Experiment	199
8.2 The Diffraction Grating	205
8.3 Single Slit Diffraction	208
8.4 The Laser	210
The Hologram	213
Other Laser Uses	215
8.5 Polarization	216
In Conclusion	220
Problems and Exercises	220
9 LIGHT AND COLOR IN NATURE	222
9.1 Rainbows and Halos	222
Rainbows	222
Halos	229
9.2 Inteference Phenomena	232
Oil Spots and Soap Bubbles	232
Coating on Glass	235
Irridescence	235
9.3 Scattering Effects	236
Rayleigh Scattering	236
Scattering by Large Particles	239
9.4 Mirages	240
9.5 The Aurora	241
In Conclusion	244
Problems and Exercises	245
APPENDIX A Calculation of the CIE Tristimulus Values	246
APPENDIX B The Spectrophotometer	253
APPENDIX C Sine Functions	257
APPENDIX D Annotated Bibliography	259
INDEX	263