

CONTENTS

| | | | |
|--|---------|--|--|
| <i>Preface</i> | page xi | | |
| <i>Acknowledgements</i> | xiii | | |
| 1 | | | |
| Directory of Plates | 1 | | |
| 2 | | | |
| Selection, Processing and Presentation of the Spectra | 7 | | |
| 2.1 Selection of Spectra | 7 | | |
| 2.2 Recording and Resolution of the Spectra | 7 | | |
| 2.3 Processing of the Spectra | 7 | | |
| 2.4 Calibration of the Wavelength | 8 | | |
| 2.5 Display of the Intensity Scale and Normalization of the Profiles | 8 | | |
| 2.6 Identification and Labeling of the Spectral Lines | 8 | | |
| 2.7 Presentation | 9 | | |
| 2.8 Object Coordinates | 9 | | |
| 2.9 Distances | 9 | | |
| 3 | | | |
| Terms, Definitions and Abbreviations | 10 | | |
| 3.1 Designation and Parameters of the Stars | 10 | | |
| 3.2 Galactic Nebulae and Star Clusters | 10 | | |
| 3.3 Extragalactic Objects | 10 | | |
| 3.4 Labeling of the H-Balmer series | 10 | | |
| 3.5 Labeling of Elements and Ions | 10 | | |
| 3.6 Abbreviations, Symbols and Common Units | 10 | | |
| 4 | | | |
| Overview and Characteristics of Stellar Spectral Classes | 13 | | |
| 4.1 Preliminary Remarks | 13 | | |
| 4.2 The Fraunhofer Lines | 13 | | |
| 4.3 Further Development Steps: The Five Secchi Classes | 14 | | |
| 4.4 “Early” and “Late” Spectral Types | 15 | | |
| 4.5 Temperature Sequence of the Harvard Classification System | 15 | | |
| 4.6 Rough Determination of the One-Dimensional Spectral Class | 15 | | |
| 4.7 Flowcharts for Estimation of the Spectral Class | 16 | | |
| 4.8 Further Criteria for Estimation of the Spectral Class | 16 | | |
| 4.9 The Two-Dimensional MK (Morgan–Keenan) or Yerkes Classification System | 18 | | |
| 4.10 Effect of the Luminosity Class on the Line Width | 18 | | |
| 4.11 Suffixes, Prefixes and Special Classes | 19 | | |
| 4.12 Statistical Distribution of Spectral Types to the Main Sequence Stars | 20 | | |
| 5 | | | |
| Spectral Class O | 23 | | |
| 5.1 Overview | 23 | | |
| 5.2 Parameters of the Late to Early O-Class Stars | 24 | | |
| 5.3 Spectral Characteristics of the O Class | 24 | | |
| 5.4 General Remarks on the Classification of O Stars | 24 | | |
| 5.5 Comments on Observed Spectra | 24 | | |
| 6 | | | |
| Spectral Class B | 30 | | |
| 6.1 Overview | 30 | | |
| 6.2 Parameters of the Late to Early B-Class Stars | 30 | | |
| 6.3 Spectral Characteristics of the B Class | 30 | | |
| 6.4 Comments on Observed Spectra | 31 | | |
| 7 | | | |
| Spectral Class A | 36 | | |
| 7.1 Overview | 36 | | |
| 7.2 Parameters of the Late to Early A-Class Stars | 36 | | |
| 7.3 Spectral Characteristics of the A Class | 36 | | |
| 7.4 Comments on Observed Spectra | 37 | | |

| | | | |
|--|----|---|----|
| 8 | | 14 | |
| Spectral Class F | 42 | Spectral Class S on the AGB | 72 |
| 8.1 Overview | 42 | 14.1 Overview and Spectral Characteristics | 72 |
| 8.2 Parameters of the Late to Early F-Class Stars | 42 | 14.2 The Boeshaar–Keenan S-Classification System | 72 |
| 8.3 Spectral Characteristics of the F Class | 42 | 14.3 “Intrinsic” and “Extrinsic” or “Symbiotic” S Stars | 72 |
| 8.4 Comments on Observed Spectra | 42 | 14.4 Hints for the Observation of S-Class Stars | 73 |
| 9 | | 14.5 Comments on Observed Spectra | 73 |
| Spectral Class G | 46 | 15 | |
| 9.1 Overview | 46 | Carbon Stars on the AGB | 78 |
| 9.2 Parameters of the Late to Early G-Class Stars | 46 | 15.1 Overview and Spectral Characteristics | 78 |
| 9.3 Spectral Characteristics of the G Class | 46 | 15.2 Competing Classification Systems | 78 |
| 9.4 Comments on Observed Spectra | 47 | 15.3 The Morgan–Keenan (MK) C-System | 79 |
| 10 | | 15.4 The Revised Keenan 1993 System | 79 |
| Spectral Class K | 53 | 15.5 Connection of the Subclasses to the Evolution of Carbon Stars | 80 |
| 10.1 Overview | 53 | 15.6 Merrill–Sanford Bands (MS) | 80 |
| 10.2 Parameters of the Late to Early K-Class Stars | 53 | 15.7 Comments on Observed Spectra | 80 |
| 10.3 Spectral Characteristics of the K Class | 54 | 16 | |
| 10.4 Comments on Observed Spectra | 55 | Post-AGB Stars and White Dwarfs | 85 |
| 11 | | 16.1 Position of Post-AGB Stars in Stellar Evolution | 85 |
| Spectral Class M | 61 | 16.2 Post-AGB Stars | 85 |
| 11.1 Overview | 61 | 16.3 Spectral Features of Post-AGB Stars | 85 |
| 11.2 Parameters of the Late to Early M-Class Stars | 61 | 16.4 White Dwarfs | 85 |
| 11.3 Spectral Characteristics of the M Class | 62 | 16.5 Spectral Characteristics and Special Features of White Dwarfs | 86 |
| 11.4 Comments on Observed Spectra | 62 | 16.6 Classification System by McCook and Sion | 86 |
| 12 | | 16.7 Comments on Observed Spectra | 86 |
| Spectral Sequence on the AGB | 67 | 17 | |
| 12.1 Evolution of Stars in the Post-Main Sequence Stage | 67 | Wolf–Rayet Stars | 89 |
| 12.2 The Spectral Sequence of the Mira Variables on the AGB | 67 | 17.1 Overview | 89 |
| 13 | | 17.2 Spectral Characteristics and Classification | 89 |
| M(e) Stars on the AGB | 69 | 17.3 Classification System for WR Stars in the Optical Spectral Range | 90 |
| 13.1 Overview | 69 | 17.4 The WR Phase in Stellar Evolution | 91 |
| 13.2 Spectral Characteristics of the M(e) Stars on the AGB | 69 | 17.5 Analogies and Differences to the Central Stars of Planetary Nebulae | 91 |
| 13.3 Comments on Observed Spectra | 70 | 17.6 Comments on Observed Spectra of the WR Classes WN, WC and WO | 91 |

| | | | |
|---|-----|--|-----|
| 18 | | 23 | |
| LBV Stars | 96 | Spectroscopic Binaries | 123 |
| 18.1 Overview | 96 | 23.1 Short Introduction and Overview | 123 |
| 18.2 Spectral Characteristics of LBV Stars | 96 | 23.2 Impact on the Spectral Features | 123 |
| 18.3 Comments on Observed Spectra | 97 | 23.3 SB1 and SB2 Systems | 125 |
| | | 23.4 Comments on Observed Spectra | 125 |
| 19 | | 24 | |
| Be Stars | 100 | Novae | 132 |
| 19.1 Overview | 100 | 24.1 The Phenomenon of Nova Outbursts | 132 |
| 19.2 Spectral Characteristics of Be Stars | 100 | 24.2 Classical and Recurrent Novae | 133 |
| 19.3 A Textbook Example: δ Scorpii | 101 | 24.3 Dwarf Novae | 133 |
| 19.4 Classification System for Be Stars | 101 | 24.4 Symbiotic Stars | 133 |
| 19.5 Comments on Observed Spectra | 101 | 24.5 Nova-like Outbursts in LBV Stars | 134 |
| | | 24.6 Evolution of the Outbursts with Classical Novae | 134 |
| 20 | | 24.7 Spectral Characteristics after Maximum Light | 134 |
| Be Shell Stars | 105 | 24.8 Evolution from the Permitted to the Nebular Phase | 134 |
| 20.1 Overview | 105 | 24.9 The Spectroscopic Tololo Classification System | 135 |
| 20.2 Spectral Characteristics of Be-Shell Stars | 105 | 24.10 Comments on Observed Spectra | 135 |
| 20.3 Comments on Observed Spectra | 105 | | |
| | | 25 | |
| 21 | | Supernovae | 142 |
| Pre-Main Sequence Protostars | 108 | 25.1 The Phenomenon of Supernova Explosions | 142 |
| 21.1 Overview | 108 | 25.2 Designation of Supernovae | 142 |
| 21.2 Herbig Ae/Be and T Tauri Stars | 108 | 25.3 Classification of SN Types | 142 |
| 21.3 Spectral Characteristics of PMS Stars | 109 | 25.4 SN Type I | 143 |
| 21.4 The FU Orionis Phenomenon | 109 | 25.5 SN Type II | 143 |
| 21.5 Comments on Observed Spectra | 109 | 25.6 Explosion Scenario: Core Collapse | 143 |
| | | 25.7 Explosion Scenario: Thermonuclear Carbon Fusion | 144 |
| 22 | | 25.8 SN Type Ia: An Important Cosmological Standard Candle | 144 |
| Chemically Peculiar (CP) Stars | 115 | 25.9 Diagram for the Spectral Determination of the SN Type | 144 |
| 22.1 Overview | 115 | 25.10 SN Type Ia: Spectral Features in the Optical Range | 145 |
| 22.2 Classification of the CP Stars | 115 | 25.11 SN Type II: Spectral Features in the Optical Range | 146 |
| 22.3 λ Bootis Class | 115 | 25.12 SN Type Ib and Ic: Spectral Features in the Optical Range | 146 |
| 22.4 Am–Fm Class | 116 | | |
| 22.5 Ap–Bp Class | 116 | | |
| 22.6 Mercury–Manganese Class | 116 | | |
| 22.7 Helium-weak Stars | 117 | | |
| 22.8 Helium-rich Stars | 117 | | |
| 22.9 Subdwarf Luminosity Class VI | 117 | | |
| 22.10 Comments on Observed Spectra | 117 | | |

| | | | |
|---|--|-----|--|
| 26 | | | |
| Extragalactic Objects | | 149 | |
| 26.1 Introduction | | 149 | |
| 26.2 Morphological Classification of Galaxies | | 149 | |
| 26.3 Spectroscopic Classification of Galaxies | | 150 | |
| 26.4 Rough Scheme for Spectroscopic Classification of Galaxies | | 150 | |
| 26.5 Absorption Line Galaxies | | 150 | |
| 26.6 LINER Galaxies | | 150 | |
| 26.7 Starburst Galaxies | | 152 | |
| 26.8 The Phenomenon of Active Galactic Nuclei (AGN) | | 153 | |
| 26.9 Seyfert Galaxies | | 153 | |
| 26.10 The Quasar Phenomenon | | 154 | |
| 26.11 Blazars and BL Lacertae Objects (BL Lacs) | | 156 | |
| 27 | | | |
| Star Clusters | | 165 | |
| 27.1 Short Introduction and Overview | | 165 | |
| 27.2 Open Clusters (OCL) | | 165 | |
| 27.3 Globular Clusters (GCL) | | 165 | |
| 27.4 Spectroscopic Analysis of Star Clusters | | 166 | |
| 27.5 Spectroscopic Age Estimation of Star Clusters by Amateurs | | 166 | |
| 27.6 The Pleiades (M45): Analysis by Individual Spectra | | 167 | |
| 27.7 Age Estimation of M45 | | 168 | |
| 27.8 Globular Clusters: Analysis by Integrated Spectra | | 168 | |
| 27.9 Age Estimation of M3, M5 and M13 | | 169 | |
| 28 | | | |
| Emission Nebulae | | 173 | |
| 28.1 Overview and Short Introduction | | 173 | |
| 28.2 H II Regions | | 173 | |
| 28.3 Planetary Nebulae | | 173 | |
| 28.4 Protoplanetary Nebulae | | 174 | |
| 28.5 Supernova Remnants | | 174 | |
| 28.6 Wolf–Rayet Nebulae | | 175 | |
| 28.7 Common Spectral Characteristics of Emission Nebulae | | 175 | |
| 28.8 Plasma Diagnostics and Excitation Class E | | 176 | |
| 28.9 Practical Aspects of the Determination of the E Class | | 176 | |
| 28.10 Practical Aspects of the Recording of Planetary Nebula | | 177 | |
| 28.11 The Excitation Class as an Indicator for Plasma Diagnostics | | 177 | |
| 28.12 Emission Lines Identified in the Spectra of Nebulae | | 178 | |
| 28.13 Comments on Observed Spectra | | 178 | |
| 28.14 Distinguishing Characteristics in the Spectra of Emission Nebulae | | 183 | |
| 29 | | | |
| Reflectance Spectra of Solar System Bodies | | 197 | |
| 29.1 Overview | | 197 | |
| 29.2 Comments on Observed Spectra | | 197 | |
| 29.3 Reflectance Spectrum of a Total Lunar Eclipse | | 198 | |
| 30 | | | |
| Telluric Molecular Absorption | | 204 | |
| 30.1 The Most Significant Molecular Absorptions by the Earth's Atmosphere | | 204 | |
| 30.2 Telluric H ₂ O Absorptions around the H α line | | 204 | |
| 30.3 Telluric O ₂ Absorptions within Fraunhofer A and B Bands | | 205 | |
| 31 | | | |
| The Night Sky Spectrum | | 209 | |
| 31.1 Introduction | | 209 | |
| 31.2 Effects on the Spectrum | | 209 | |
| 32 | | | |
| The Mesospheric Sodium Layer | | 211 | |
| 32.1 Overview | | 211 | |
| 32.2 Spectroscopic Detection of the Sodium Layer | | 211 | |
| 33 | | | |
| Terrestrial and Calibration Light Sources | | 213 | |
| 33.1 Spectra of Common Gas Discharge Lamps | | 213 | |
| 33.2 Spectra of Glow Starters Modified as Calibration Light Sources | | 214 | |
| 33.3 Calibration and Processing of an Entire Echelle Spectrum | | 215 | |
| 33.4 Spectra of Hydrocarbon Flames | | 215 | |
| 33.5 Terrestrial Lightning Discharges | | 215 | |

| | | | |
|---|-----|---|-----|
| Appendix A: Spectral Classes and $v \sin i$ Values of Bright Stars | 243 | Appendix H: Distant AGN and Quasars Brighter than $m_v \approx 16$ | 259 |
| Appendix B: The 88 IAU Constellations | 247 | Appendix J: Excerpts from Historical Spectral Atlases | 262 |
| Appendix C: Spectral Classes and B–V Color Index | 249 | Appendix K: Instruments | 265 |
| Appendix D: Spectral Classes and Effective Temperatures | 251 | Bibliography | 266 |
| Appendix E: Excitation Classes of Bright Planetary Nebulae | 253 | Subject Index | 275 |
| Appendix F: Ionization Energies of Important Elements | 255 | Stellar Index | 278 |
| Appendix G: Spectroscopic Measures and Units | 257 | Object Index: Deep Sky and Solar System | 279 |