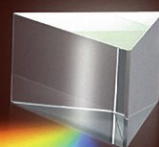


Ken M. Harrison

Astronomical Spectroscopy for Amateurs



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**Astronomical
Spectroscopy for
Amateurs**

Ken M. Harrison

 Springer

Ken M. Harrison
Cobham, UK

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ISSN 1431-9756

ISBN 978-1-4419-7238-5

e-ISBN 978-1-4419-7239-2

DOI 10.1007/978-1-4419-7239-2

Springer New York Dordrecht Heidelberg London

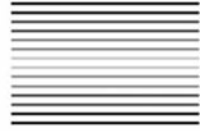
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Preface

There have been three significant milestones in the history of observational astronomy: the invention of the telescope, photography, and the spectroscope. The development of the spectroscope has contributed more to the science than any other telescope accessory. It has been said that 85% of all astronomical discoveries have been made with the spectroscope.

Probably due to the perception that lots of mathematics and calculations are involved, plus the fact that it doesn't have the "Ohh" or "Ahh" impact of some of the spectacular astronomical images now being regularly distributed on the forums and websites, spectroscopy is an area that has been long overlooked and neglected by the amateur. By using amateur telescopes, mountings, and CCD cameras currently available, this book will show how, with the addition of a simple spectroscope we can observe and record spectra that reveal the temperature, composition, and age of stars, the nature of the glowing gases in nebulae, and even the existence of other exoplanets circling around distant stars.

The basic challenge facing the novice is where to start. What equipment will I need? Where can I find a spectroscope? How do I process the CCD image? How do I analyze my first spectrum? These questions and more are addressed in this book. Up to date information on equipment, spectroscopes, and methods available to the amateur, and more importantly "How to. . ." are all included in this book.

There are three basic sections in this book:

1. Introduction to Spectroscopy. This part provides a brief overview of the history of spectroscopy, the theory behind the spectrum lines, and types of spectroscopes.
2. Obtaining and Analyzing Spectra. Tells how to set up and use your spectroscope; describes different commercially available spectroscopes, cameras, and CCD's; explains how to analyze your spectra; and presents some interesting amateur projects.



3. Spectroscopy Design and Construction. Here you will find basic spectroscopy design ideas and how to construct your own spectroscopy.

Each section is independent of the other, so if you want to jump straight into taking your first spectrum, go to the second section and get started!

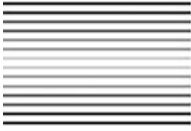
“Spectroscopy” is the generic term for visual spectroscopes, spectrographs (imaging), and spectrometers (linear CCD measuring devices). (Telescopes are not given different names when used with eyepieces, cameras, or filters, so why should spectroscopes?!)

Units of measure are always an issue of debate. Both the SI unit nanometer (nm) and Angstrom units (\AA) are widely used in spectroscopy as a measure of wavelength, as are measurements and sizes in millimeters rather than inches.

As you gain practice and experience you may want to increase the resolution of your spectroscopy, contribute to the ever-growing list of amateur and pro-am projects, or even construct your own spectroscopy. The various sections in this book will guide you through the issues and hopefully answer your questions on all the different aspects of spectroscopy. It’s a new and challenging field for amateurs, and with even the most basic of equipment it can be interesting, thought provoking, and most of all fun!

Cobham, UK
February 2010

Ken M. Harrison



Contents



PART ONE Introduction to Spectroscopy

1 Early Experiments in Spectroscopy	3
For Further Reading	8
Web Pages	8
2 A History of Astronomical Spectroscopy	9
Further Reading	14
Web Pages	14
3 Theory of Spectra	15
Kirchhoff's Laws	15
Black Body Radiation	16
Quantum Theory	17
Forbidden Lines	18
Doppler and Red Shifts	20
Solar Spectrum	21
Stellar Spectra	22
The H-R Diagram	22
HD Classifications	23
Standard Spectral Lines and Reference Spectra	25
Flouro Spectrum	26
Other Useful Spectral Reference Lines	26
Airy Disk, Rayleigh Limits, and FWHM, PSF	28

Focus and Exit Pupil	31
Exit Pupil and Eye Relief	33
Further Reading	33
Web Pages	34
4 Prisms, Gratings and Spectroscopes	35
Dispersion, Plate Scale, and Resolution	35
Efficiency of Your Spectroscope	36
Prisms	37
Resolution	38
Efficiency of a Prism Spectroscope	38
Amici Prism Systems	39
Gratings	39
Grating Theory	40
Further Reading	44
Web Pages	44
5 Types of Spectroscopes	45
Objective Prism or Grating	45
Prism with Collimator/Camera-CCD	46
Traditional Prism Littrow	46
Transmission Grating in Converging Beam	47
Transmission Grating in Collimated Beam (with or without Slit)	48
Grisms	48
Reflection Grating (with or without Slit)	49
Further Reading	53
Web pages	53

PART TWO Obtaining and Analyzing Spectra

6 Setting Up the Spectroscope	57
Objective Prisms/Gratings	57
Camera Lenses	57
Telescopes	57
Mounting the Objective Prism/Grating	58
Objective Prisms	58
Objective Gratings	58
Adjustments and Focus	60
Prisms	60
Gratings	61
Flats and Darks	63
Web Pages	63
7 Using Spectroscopes in the Converging Beam	65
Obtaining Your First Spectrum	67
Points to Note	67

- Camera Response vs. Recorded Spectra 68
- Using Other Transmission Gratings 69
- Using Gratings in a Collimated Beam 70
- Web Pages 72
- 8 Reflection Grating Spectroscopes 73**
 - Mounting the Spectroscope 74
 - Getting a Star Focused on the Slit 76
 - Beamsplitters and Non-reflective Slits 77
 - SBIG Software Controlled Spectroscopes 77
 - Baader DADOS Spectrograph 79
 - Shelyak's LhiresIII 80
 - Questar QMax Solar Spectrometer 81
 - Other Spectroscopes 82
 - The eShel Spectrograph from Shelyak 82
 - The Baader BACHES Echelle Spectroscope 83
 - The Optomechanics 10 C 84
 - Remote Control of Spectroscopes 84
 - Web Pages 85
- 9 Cameras and CCD's 87**
 - CCD Chip Size 87
 - Pixel Size 87
 - Quantum Efficiency 89
 - Bayer Matrix 89
 - Bias, Darks, and Flats 92
 - Spectroscope Flats 93
 - Further Reading 95
 - Web Pages 95
- 10 Processing Spectra 97**
 - Preparing the Raw Image for Processing 98
 - Grating Spectra: Linear Dispersion 98
 - Smile and Tilt 99
 - Visual Spec (VSpec) 100
 - Standard Stellar Spectra 100
 - Standard Element Lines 101
 - Obtaining a Spectral Pixel Profile 101
 - Wavelength Calibration 102
 - Camera Response 104
 - Correcting Spectra Using the Camera Response Curve 107
 - Using the CCD QE Curves – Response Curve 107
 - Calibrating Using a Reference Lamp 108
 - Resolution 108
 - Normalized Spectrum 108
 - Signal to Noise Ratio (SNR) 108

Continuum Removal	109
Equivalent Width (LEQ)	109
Web Pages	109
11 Amateur Spectroscopy Projects	111
Solar Spectrum	111
Astronomical Filters	112
Stellar Classification	114
Emission Stars (Be and WR)	114
Doppler Shift – Binary Stars/Exoplanets/Quasars	117
Variable Stars, Nova, and Supernovae	119
Nebulae	121
Comets	123
H α Observing of Solar Prominences	124
Meteors	125
Planetary Spectroscopy	127
Further Reading	129
Web Pages	129

PART THREE Spectroscopy Design and Construction

12 Design Basics	133
The Entrance Slit	135
Classic Semi-fixed Entrance Slit	138
Adjustable Entrance Slits	139
Commercial Slits	139
Setting the Slit Gap	140
Projection Method	141
Other Slit Alternatives	142
Photographic Negative for Slit	142
The Collimator	143
The Prism as a Dispersion Element	144
Resolution	147
Abbe Numbers	148
Gratings as a Dispersion Element	148
Blazed Gratings	148
Anamorphic Factor	150
The Imaging Lens	151
The Eyepiece/Camera/CCD	152
Attaching and Focusing the Camera/CCD	153
Spectroscopy Design Summary	153
Assumptions	155
Calculations	156
Reference Lamps	159
Testing and Calibrating Spectroscopes	160

- Laser Collimator 161
- Testing the Collimator Alignment and Focus 162
- Optical Testing 162
- Calibration 163
- Web Pages 165
- 13 Prism Spectroscope Designs 167**
- Objective Prisms 167
- Other Prism Spectroscopes 169
 - Prisms in Collimated Beams 169
- Traditional Prism Spectroscope 171
 - Classic Littrow Prism Spectroscope 172
 - Efficiency of a Prism Spectroscope 173
- Further Reading 173
- Web Pages 173
- 14 Transmission Grating Spectroscope Designs 175**
- Objective Gratings 175
- Converging Beam Arrangement 175
 - Aperture Mask 181
 - Adding a Grism 182
 - Adding a Slit 184
 - Mounting Other Transmission Gratings in a Converging Beam 186
 - Improving Resolution with a Collimator Lens 188
 - Using a Barlow Lens as a Collimator 189
- Watkis Transmission Grating Spectroscope 189
- Tragos Design 190
- LORIS Design 192
- Further Reading 193
- Web Pages 193
- 15 Reflection Grating Spectroscope Designs 195**
- Classic Design 195
 - Construction Notes 196
 - Grating Adjustments 198
 - Dust 198
- Littrow Design 198
 - Construction Notes 199
 - Grating Housing and Adjustment 200
 - Camera/Focuser 201
 - Reference Light Source 202
 - Slit Back Light Arrangement 203
- WPO Design 203
- Ebert-Fastie Design 205
- Czerny-Turner Design 209
- Echelle Spectroscopes 209

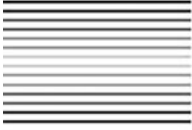
- Fiber Optics 210
 - Aperture Ratio, F/Ratio, and Numerical Aperture (NA) 211
 - Fiber Optic Applications 211
- Other Amateur Designs 212
 - Mete 212
 - Kaye 214
 - Glumac 217
 - Bareges CCD Spectrograph (Rondi/Buil) 217
- Further Reading 217
- Web Pages 217
- 16 Guiding, OAG, Beamsplitters, and Flip Mirrors 219**
 - Off-Axis Guiders 219
 - Beamsplitter Spectroscope Applications 219
 - Modifying a Vixen Flip Mirror to a Beamsplitter 220
 - Fitting and Adjusting the Beamsplitter Plate 223
 - Using the Beamsplitter 224
 - Dove Prism as Beamsplitter 224
 - Transfer Systems for Guide Cameras 226
 - Split Mirror Guider 226
 - Further Reading 228
 - Web Pages 228
- Appendix A 229**
 - Suppliers of Spectroscopes and Accessories 229
 - Star Analyser Grating 229
 - Rainbow Optics Star Spectroscope 229
 - SGS and DSS-7 Spectroscopes 229
 - Shelyak Lhires III 230
 - Baader DADOS Spectrograph 230
 - Rigel Systems 230
 - QMax Spectrograph 230
 - Gratings 230
 - Prisms 231
 - Entrance Slits 231
 - Lenses and Mirrors 231
 - Electroluminescent Panels 231
- Appendix B 233**
 - Useful Spectroscopy Forums and Other Websites 233
- Appendix C 235**
 - Selected Bibliography 235
- Appendix D 237**
 - Extras 237
- Index 239**



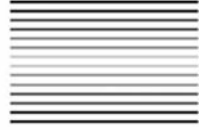
About the Author

A keen amateur astronomer, Ken Harrison was born in Scotland where he trained as a mechanical engineer. He has been designing and building telescopes since the early 1960's and has built a series of spectroscopes for use on medium sized amateur telescopes. He was Section Director of the Astronomical Society of Victoria, Australia, Astrophotographic Section for 10 years and past President of the Society. Ken's university thesis (and his first publication) was *Design and Construction of the Isaac Newton 98-inch Telescope* (Strathclyde University, 1970). Since then he has published articles on optical design including "Blink Comparison" (BAA Journal Vol 87, p 94) and "Method of Radially Supporting Large Mirrors" (Vol 87, p 154). He has made contributions to the Astronomical Society of Victoria Newsletter and was for 3 years the Editor of the "N'Daba" newsletter of the Natal Centre, Astronomical Society of Southern Africa.

PART ONE



**Introduction to
Spectroscopy**



CHAPTER ONE



Early Experiments in Spectroscopy

To the ancient Greeks and other philosophers around the world, light was all-pervasive and a medium connecting visible objects. Aristotle's view of light was something all bodies could have, similar to the element of fire. Early religions associated light with the Sun (as well as heat and life-giving energy) and accepted that it was a gift from the gods. Robert Grosseteste in the early thirteenth century declared light to be the "prima material," the original substance from which the universe was made, "for every natural body has in itself a celestial luminous nature and luminous fire."

The rainbow should have given philosophers cause to ponder more about the nature of light. Instead they rationalized it to be a sign from the gods. For Christians, it was God's covenant that never again would there be a flood like that experienced by Noah (see Fig. 1.1).

Al Farisi and Theodoric of Freiberg around A. D. 1300 showed how the geometry of the raindrop could produce a rainbow, but it wasn't until much later, in 1670, that Isaac Newton (1642–1727) applied his scientific reasoning to the analysis of the Sun's spectrum. He allowed a small beam of sunlight to go through his prism and produce a spectrum. With this he showed that white light is made up of many colors. The original red, yellow, green, blue, and violet were augmented by orange and indigo (to make up a "perfect seven"). ROY G BIV has become our rainbow ever since.

With his experiments in "refraction" Newton concluded that lenses would never give a color-free image (chromatic aberration) and went on to develop his reflecting telescopes as an alternative (see Fig. 1.2).

After Newton there was a hiatus in the scientific use of prisms, and it wasn't until 1750 that a Scot, Thomas Melvill (1726–1753) noted that by adding "burning spirit" to his candle, his prism showed a band of yellow light. At about the same time, John



Figure 1.1. *A Lesson In The Rainbow*, late fourteenth-century manuscript of “De proprietatibus rerum.” (On the Property of Things) by Bartholomaeus Anglicus.

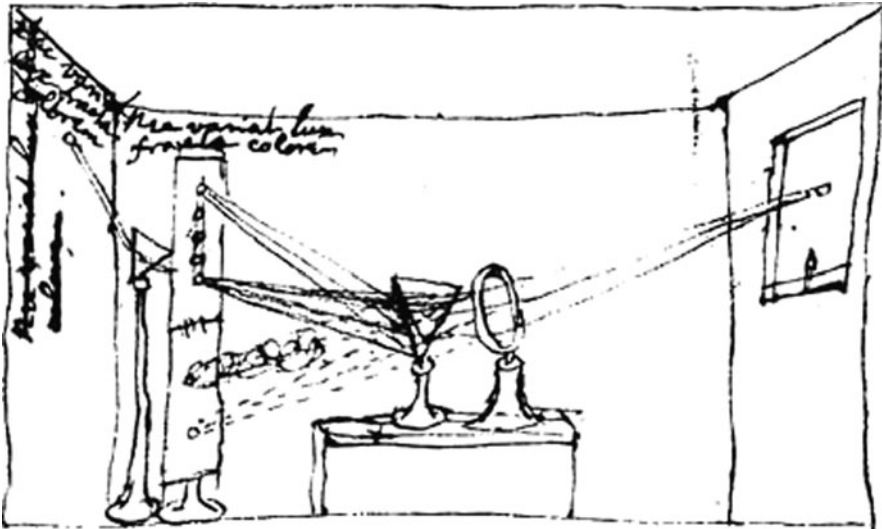


Figure 1.2. Newton's prism experiments. (Courtesy New College Library.)

Dollond (1706–1761), an English optician, appreciated that not all glass dispersed light by the same amount; he found (in 1758) that by combining a clear crown glass and a leaded flint glass that the chromatic aberrations could be significantly reduced. Here we have the first evidence of appreciation that the spectrum produced by different types of glass was different enough to be useful.

There is very little recorded evidence of other spectral experiments in the 1700's until William Herschel (1738–1822) was finally persuaded by his colleague William Watson (1715–1787) to experiment with a prism to view the spectra of the brighter stars. In 1797 he recorded the distribution and intensity of the various colors in the spectra, but did not pursue the interest.

William Hyde Wollaston (1766–1828) improved his view of the solar spectrum by adding an “elongated crevice, 1/20'' wide” between the prism and the Sun. This showed him seven distinct dark lines in the spectrum (1802); these he associated with the “natural boundaries” between the colors. Such was the state of knowledge in the early 1800's.

Fraunhofer Lines

Label	Wavelength (nm)	Source
A-band	759.4–762.1	Atmospheric O ₂
B-band	686.7–688.4	Atmospheric O ₂
C	656.3	H α
α -band	627.6–628.7	
D1	589.6	Na I
D2	589.0	Na I
E	526.9	Fe I
b1	518.4	Mg I
b2	517.3	Mg I
c	495.8	Fe I
F	486.1	H β
d	466.8	
e	438.3	Fe I
f	434.0	H γ
G	430.8	Ca/Fe (430.77/430.79)
g	422.7	Ca I
h	410.2	H δ
H	396.8	Ca II
K	393.3	Ca II

Josef von Fraunhofer (1787–1826) took up the challenge to measure the dispersion of the glass he was producing. At this time there was very little scientific analysis carried out in the manufacture of glass; making glass was an art, not a science. There was a degree of trial and error every time!

By making small prisms from each batch of glass and measuring and recording the dispersion, Fraunhofer could quickly ensure that the process was giving the outcome he needed. This allowed him to manufacture the best objectives of the time, and his large telescopes were the envy of all astronomers. He designed and built the 9.5" Great Dorpat Refractor in 1824, mounting it on his new "German Equatorial mount."

To improve his measuring device, which he called a "spectroscope," he added a slit in front of the collimating lens; this gave a cleaner image of the spectrum. He also noticed that sunlight, when dispersed by his prisms, always seemed to have dark lines in the same positions, and eventually, in 1815, he mapped some 324 lines; the more prominent ones are still called "Fraunhofer lines". See Fig. 1.3. Although he didn't understand how these lines were produced, he made good use of them as "standard wavelengths" for his optical testing.

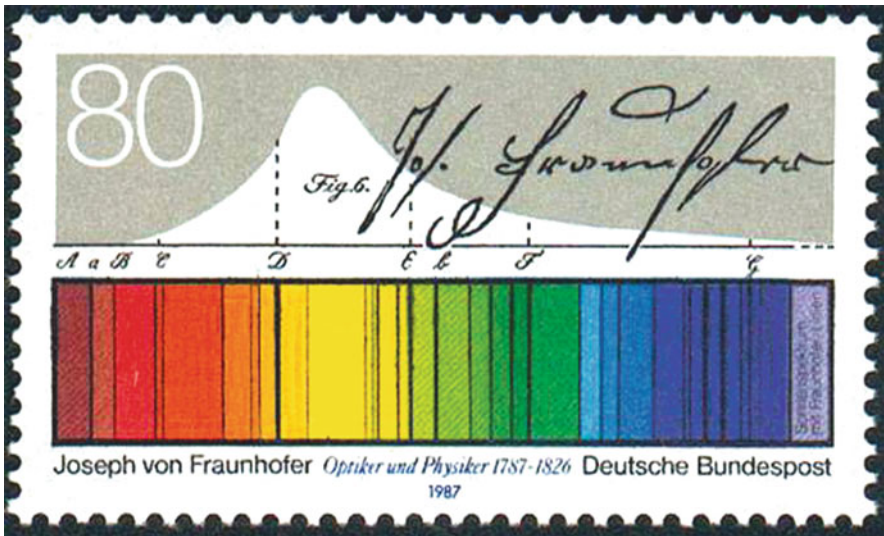


Figure 1.3. Fraunhofer's spectrum. (Photo courtesy of NASA.)

Fraunhofer also placed a prism in front of his telescope objective (in 1823) and observed the stars and planets. He noted that similar lines appeared in the stellar spectra. This very first objective prism is currently on display in the Deutsches Museum in Munich. See Fig. 1.4.

To further improve his spectral measurements he developed the diffraction grating. Early examples were made by winding fine wire around a frame. With these

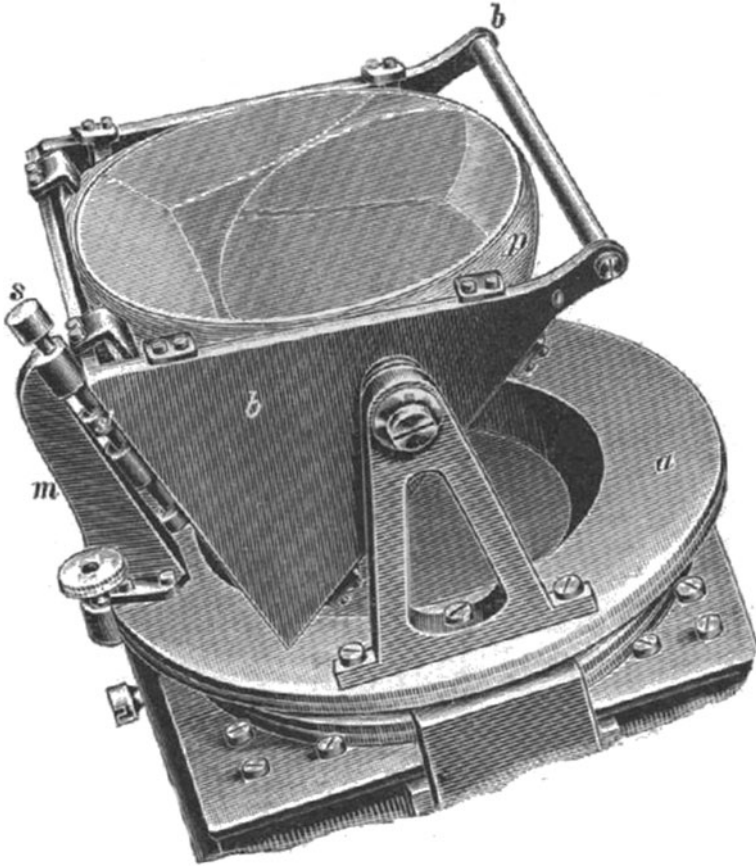


Figure 1.4. Fraunhofer's early objective prism. (From Dr. L. Ambronn, "Handbuch der Astronomischen Instrumentenkunde- II Band", 1899.)

gratings, which gave the spectrum a more uniform scale, it was easier to accurately measure the position of the various dark lines.

It can therefore be said that Fraunhofer was certainly the father of spectroscopy. He invented and developed the spectroscope to the stage that it could be used as a scientific tool to view and measure spectra.

Giovanni Amici (1786–1863), director of the Florence Observatory in Italy, employed a combination of crown and flint prisms in his dispersion prism arrangement that effectively gave a straight through, undeviated spectrum. This "Amici prism" design was widely used in subsequent Direct Vision star spectroscopes.

It was in 1859 that Gustav Kirchhoff (1824–1887) and Robert Bunsen (1811–1899) finally solved the problem of the dark (and bright) lines in the spectrum. Their experiments showed conclusively that various elements gave rise to their own unique bands (always in the same position) in the spectrum. With this

connection now established many chemists took up the challenge and established a database of element lines.

Kirchhoff, in furthering his investigations, developed his three laws:

- (1) An incandescent solid or a gas under high pressure will produce a continuum spectrum.
- (2) An incandescent gas under low pressure will produce an emission-line spectrum.
- (3) A continuous spectrum viewed through a low-density gas at low temperature will produce an absorption-line spectrum.

The era of scientific research had begun. No more rainbows!

For Further Reading

Abbott, D. (Ed.), *The Biographical Dictionary of Scientists-Astronomers*. Blond Educational (1984).

Web Pages

<http://home.vicnet.net.au/~colmusic/clario2.htm>

CHAPTER TWO



A History of Astronomical Spectroscopy

The publication of Kirchhoff's and Bunsen's work brought the awareness of the spectroscope, and what it could reveal, to a wider audience, including astronomers. The obvious question was, how could this new instrument be used to analyze the light from the Sun and stars?

Auguste Comte (1798–1857), a French philosopher stated this in 1835: “We may in time ascertain the mean temperature of the heavenly bodies: but I regard this order of facts as for ever excluded from our recognition. We can never learn their internal constitution, nor, in regard to some of them, how heat is absorbed by their atmosphere.” He was about to be proved wrong!

One of the first astronomers to apply the spectroscope to his telescope was William Huggins (1824–1910), an English amateur. To quote from his later book:

I soon became a little dissatisfied with the routine character of ordinary astronomical work, and in a vague way sought about in my mind for the possibility of research upon the heavens in a new direction or by new methods. It was just at this time ... that the news reached me of Kirchhoff's great discovery of the true nature and the chemical constitution of the sun from his interpretation of the Fraunhofer lines.

This news was to me like the coming upon a spring of water in a dry and thirsty land. Here at last presented itself the very order of work for which in an indefinite way I was looking – namely, to extend his novel methods of research upon the sun to the other heavenly bodies. A feeling as of inspiration seized me: I felt as if I had it now in my power to lift a veil which had never before been lifted; as if a key had been put into my hands which would unlock a door which had been regarded as for ever closed to man – the veil and the door behind which lay the unknown mystery of the true nature of the heavenly bodies.

For the next 40 years he and his wife Margaret dedicated their time and resources to observing the sky with the spectroscope.

Huggins designed and built all his prism spectroscopes and pioneered new techniques such as providing a reference spectrum from an electric spark and a reflection slit to improve guiding the spectroscope on a star. See Fig. 2.1.

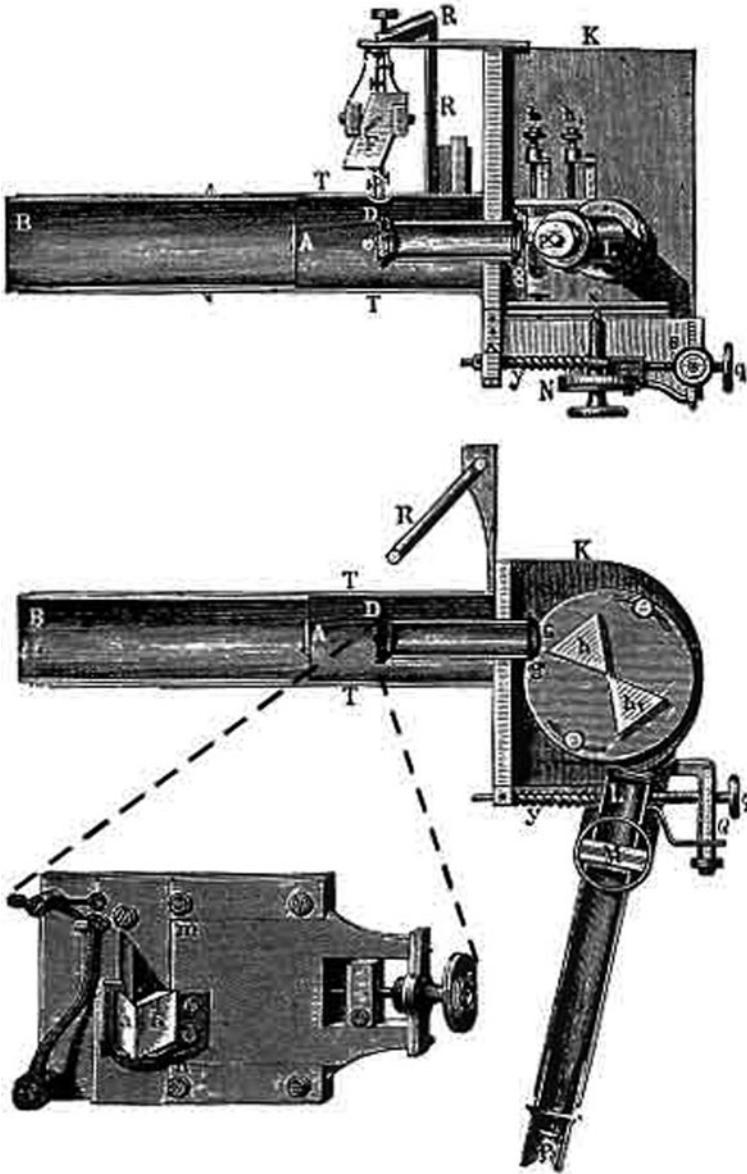


Figure 2.1. Huggins spectroscope. (WIKI.)

From his observatory at Tulsa Hill just outside London, Huggins was the first to observe emission lines in the spectra of nebulae; he also correctly applied Doppler's principle to his spectra to determine the radial velocity of a star (Sirius). In 1869, Huggins developed a technique to allow the observation of solar prominences without the need for a solar eclipse. He later also correctly identified the ultraviolet lines of hydrogen on photographic plates.

Another active observer at the time was Father Angelo Secchi (1818–1878) of the Vatican Observatory. Secchi observed the spectra from over 4,000 stars and developed a stellar classification system that was used for almost 50 years.

In 1863 he announced his Class I (strong hydrogen lines) and Class II (weaker hydrogen lines with numerous metallic lines) stars; by 1866 he had added Class III (bands stronger towards the blue, plus metallic lines), and in 1868 Class IV (deep red stars with bands opposite to Class III). He later added Class V (emission spectra). See Fig. 2.2.

The Mertz 12° objective prism 162 mm diameter (made in 1872) used by Secchi for his later research, was displayed at the 2009 ASTRUM exhibition in Rome.

Anders Jonas Angstrom (1814–1874), using an early grating spectroscope, mapped the solar spectrum with greater accuracy than had been done previously. In 1868 he published an atlas of over 1,000 lines, their positions recorded in units of 10^{-10} m. This is now known as Angstrom Units (Å) and is still widely used.

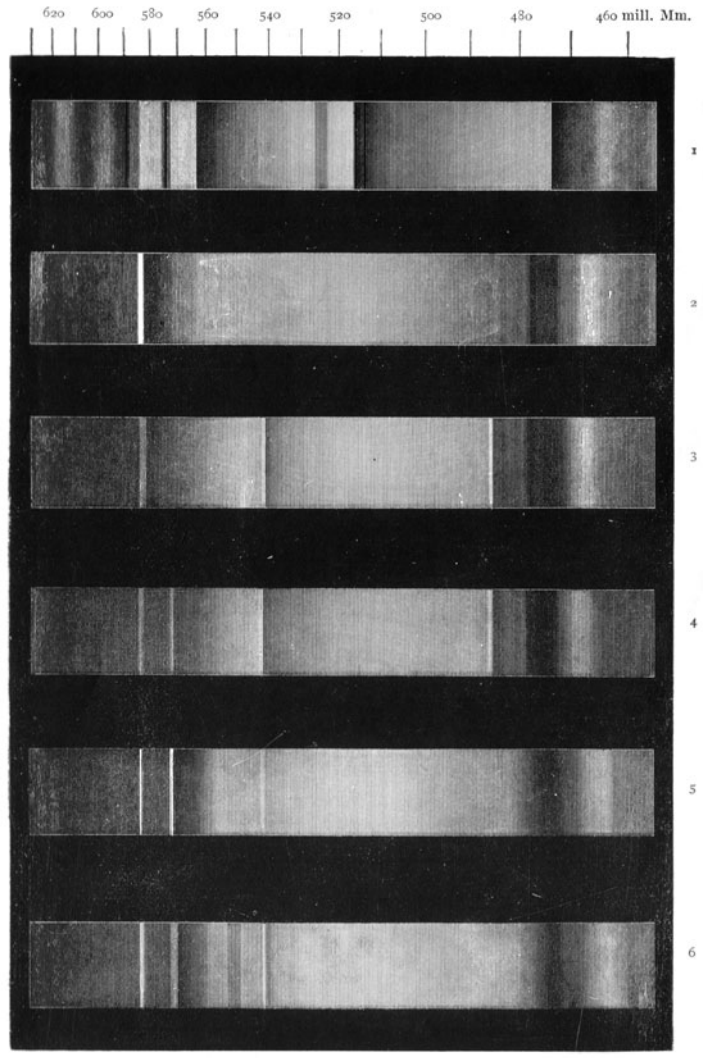
Henry Draper (1837–1882) succeeded in obtaining a photograph of the spectrum of Vega, which clearly showed the hydrogen absorption lines (1872). The advent of the dry photographic plate in the mid-1880s allowed early investigators to carry out the long exposures required to record spectra (Harvard Observatory obtained the first spectrum of a meteor in 1897). The use of these dry plates and later photographic film heralded the beginning of the transfer of spectroscopy from amateurs to professional astronomers.

With monies from the Henry Draper Memorial Fund, Edward Pickering (1846–1919) and his team at Harvard Observatory followed the work of Secchi in recording and cataloging stellar spectra. Using an objective prism mounted in front of the telescope objective he was able to quickly amass large amounts of low resolution spectra (He used objective prisms with angles from 5 to 7° mounted on telescopes up to 13" aperture to obtain the spectra). The subsequent "Henry Draper Catalogue" of stellar spectra was based on separate classes and sub classes; W O B A F G K M. Updated and enhanced versions of this catalog are still used today.

The work of Henry Rowland (1848–1901) in perfecting his grating ruling engine in 1882 allowed the production of large diffraction gratings that gradually took over from prisms in professional spectroscopes.

By the turn of the century the era of the amateur scientist was drawing to a close; larger and larger spectroscopes and telescopes were producing scientific results that would determine the direction of astrophysics for the next 100 years.

The interested amateur could acquire spectroscopes made by John Browning (1835–1925). These were small direct-vision Amici prism instruments (D-V) for stellar observing, and they established the trend for the next 40 years. Being a dedicated visual instrument, the results were limited to viewing spectra of the Sun, brighter stars, and nebulae.



VISUAL SPECTRA TYPE V COMPARED WITH TYPE IV (VOGEL).
1. γ Can. Ven. ; 2. XVIII^h 3^m, S. 21° 16'; 3. VI^h 51^m, S. 23° 49'; 4, 5, 6. Wolf-Rayet, Nos. 1, 2, 3, Cygnus.

Figure 2.2. Visual spectra of Secchi Type IV and V by Vogel. (From Preface to Webb's Celestial Objects for Common Telescopes, 1917.)

Commercial D-V instruments continued to be produced by Adam Hilger, Ltd., among others and examples by GOTO (Japan) and LaFayette (USA) were widely used by amateur astronomers in the 1950's and 1960's (see Fig. 2.3).