Spectroscopy is the study of the different wavelengths/frequencies of light we see from an object. It is a measure of the quantity of each colour of light (or more specifically, the amount of each wavelength of light). It is a powerful tool in astronomy. In fact, most of what we know in astronomy is a result of spectroscopy: it can reveal the temperature, velocity and composition of an object as well as be used to infer mass, distance and many other pieces of information. Spectroscopy is done at all wavelengths of the electromagnetic spectrum, from radio waves to gamma rays; but here we will focus on optical light.
wavelength

650 nm

wavelength

400 nm
**light source**
- A hot solid

**absorption**
- A hot gas at high pressure
- A cold gas at a low pressure

**prism**

**result**
- Continuous spectrum
- Emission line spectrum
- Absorption line spectrum
Equipment – Visual Spectroscopy

- Prism
- CD or DVD
- Naked Eye
Equipment – Telescopic Spectrographs

More Expensive – R15,000 to R85,000

- SBIG
- Baader DADOS
- Lhires Lite

Less Expensive – R2,000 to R3,000

- Rainbow Optics Star Spectroscopes
- The Star Analyser 100 (SA-100 or 200)
$\Delta E = hv$
**GROUND STATE**
A hydrogen atom in its Ground State. The electron occupies the lowest possible energy level which in the case of hydrogen is the Principal Quantum Level $n = 1$.

**EXITED STATE** – absorbs energy – a specific amount of photon energy
A hydrogen atom in an Excited State. The electron occupies one of the higher energy levels further from the nucleus of the atom.
Ground State

Electron Transitions from higher energy levels all to the n = 2 level in a sample of Hydrogen atoms

Atomic Emission Spectrum

656.3 nm  Balmer Series - Visible Region  486.1 nm  434.0 nm  410.2 nm
Increasing Wavelength  Increasing Frequency
Exited State (absorb energy)

Electron Transitions from higher energy levels all to the $n = 2$ level in a sample of Hydrogen atoms

Atomic Emission Spectrum

656.3 nm  Balmer Series - Visible Region  486.1 nm  434.0 nm  410.2 nm

$\text{H}\alpha \, 6563 - n_2 / n_3$
$\text{H}\beta \, 4861 - n_2 / n_4$
$\text{H}\gamma \, 4340 - n_2 / n_5$
$\text{H}\delta \, 4101 - n_2 / n_6$
Blamer Series (emits energy)

Electron Transitions from higher energy levels all to the $n = 2$ level in a sample of Hydrogen atoms

Atomic Emission Spectrum

Balmer Series - Visible Region

Increasing Wavelength

Increasing Frequency

656.3 nm  Balmer Series - Visible Region  486.1 nm  434.0 nm  410.2 nm

Hα 6563 – $n_3 / n_2$

Hβ 4861 – $n_4 / n_2$

Hγ 4340 – $n_5 / n_2$

Hδ 4101 – $n_6 / n_2$
### TABLE O1

**Overview on the spectral classes**

<table>
<thead>
<tr>
<th>Spectral Class</th>
<th>Temperature (°K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O9.5</td>
<td>26'000°K</td>
</tr>
<tr>
<td>B1</td>
<td>22'000°K</td>
</tr>
<tr>
<td>B7</td>
<td>15'000°K</td>
</tr>
<tr>
<td>A1</td>
<td>10'000°K</td>
</tr>
<tr>
<td>A7</td>
<td>7'550°K</td>
</tr>
<tr>
<td>F0</td>
<td>7'030°K</td>
</tr>
<tr>
<td>F5</td>
<td>6'330°K</td>
</tr>
<tr>
<td>G2</td>
<td>5'700°K</td>
</tr>
<tr>
<td>G8</td>
<td>4'990°K</td>
</tr>
<tr>
<td>K1.5</td>
<td>4'290°K</td>
</tr>
<tr>
<td>K5</td>
<td>3'950°K</td>
</tr>
<tr>
<td>M1.5</td>
<td>3'600°K</td>
</tr>
<tr>
<td>M5</td>
<td>3'300°K</td>
</tr>
</tbody>
</table>

The table also includes wavelengths for various spectral lines, such as He I 4371, He II 4686, C III 4647/51, and others.
**Class O - Lamda Orionis - Blue > 30,000K**

- Class O stars are very hot and very luminous, being bluish in color. These are the rarest of all main sequence stars.
- Helium is very difficult to ionize, so spectral lines by ionized Helium (He II) only appear in these hot stars, prominent ionized Si IV, OIII, NIII, CIII,

**Class B - Rigel, Spica - Blue-White 9500K - 30,000K**

- Class B stars are extremely luminous and blue
- They are hot enough to energize their Helium, but are not hot enough to ionize it. Thus B stars have Hel lines (neutral He) but do not have HeII lines
- Ionized metal lines include MgII, SiII
- “B & O stars” – stars with temp’s > 10,000 K, most of the Hydrogen gas in the star’s atmosphere will be ionized. Since an ionized Hydrogen atom has no electron it cannot produce any spectral lines, thus the Hydrogen lines are weak

**Class A - Sirius, Vega, Altair - White 7000K - 9500K**

- Class A stars are amongst the more common naked eye stars, and are white or bluish-white.
- They have strong hydrogen lines and also lines of ionized metals FeII, MgII, SiII, CaII
- They do not have any Helium lines at all

**Class F - Canopus, Procyon - Yellow-White 6000K - 7000K**

- Class F stars have strengthening CaII lines + neutral metals FeI, CrI
- These stars are within the right range of temperatures to energize their Hydrogen gas without ionizing it. Thus the Hydrogen “Balmer” lines are very strong in these stars.
Class G - The Sun, Capella - Yellow 5200K – 6000K

• Most notable are the lines of CaII.
• They have even weaker hydrogen lines than Class F, but along with the ionized metals, they have neutral metals.

Class K - Arcturus, Aldebaron - Orange 3900K – 5200K

• Class K are orangish stars which are slightly cooler than our Sun.
• Some K stars are giants & supergiants.
• They have extremely weak hydrogen lines, if they are present at all, and mostly neutral metals MnI, FeI, SiI.
• By late K, molecular bands of TiO become present.

Class M - Antares, Betelguese - Red < 3900K

• Class M are most common.
• The spectrum of an M star shows lines belonging to molecules and all neutral metals but hydrogen lines are usually absent. Titanium oxide can be strong in M stars. Vanadium oxide bands are also seen in late M stars.

Class W or WR - Wolf-Rayet stars – Gamma Velorum

• Unusual since they have mostly helium in their atmospheres instead of hydrogen. They are thought to be dying supergiants with their hydrogen layer blown away by hot stellar winds caused by their high temperatures, thereby directly exposing their hot helium shell. They show spectral lines of carbon, nitrogen, or oxygen emission in their spectra (and outer layers).
• These lower temp stars, the Hydrogen gas isn’t as easily excited, thus the Balmer lines aren’t as strong
Class W: Wolf-Rayet

Class G & M

Class B
## Common Spectral Lines (given in Å):

### Hydrogen (the “Balmer Series”):
- Hα 6563
- Hβ 4861
- Hγ 4340
- Hδ 4101
- He λ 3970
- H8 3889
- H9 3835
- H10 3798
- H11 3771
- H12 3750

### Helium:
- He I 4026, 4388, 4471, 4713, 5015, 5048, 5875, 6678,
- He II 4339, 4542, 4686, 5412

### Metals:
- C II 4267
- C III 4649, 5696
- C IV 4658, 5805
- N III 4097, 4634
- N IV 4058, 7100
- N V 4605
- O V 5592
- Na I 5890, 5896
- Mg I 5167, 5173, 5183
- Mg II 4481
- Hg 4358, 5461, 5770, 5791

### Molecular Bands:
- CH “G band” 4300
- CN 3880, 4217, 7699
- C2 “Swan” 4380, 4738, 5165, 5635, 6122
- C3 4065
- MgH 4780
- TiO 4584, 4625, 4670, 4760

### Visible Continuous Spectrum 2
(Perceived Brightness Partially to Scale)
<table>
<thead>
<tr>
<th>Lines</th>
<th>Due To</th>
<th>Wavelengths</th>
<th>Lines</th>
<th>Due To</th>
<th>Wavelengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - (band)</td>
<td>O₂</td>
<td>7594 - 7621</td>
<td>F</td>
<td>H</td>
<td>4861</td>
</tr>
<tr>
<td>B - (band)</td>
<td>O₂</td>
<td>6867 - 6884</td>
<td>d</td>
<td>Fe</td>
<td>4668</td>
</tr>
<tr>
<td>C</td>
<td>H</td>
<td>6563</td>
<td>e</td>
<td>Fe</td>
<td>4384</td>
</tr>
<tr>
<td>a - (band)</td>
<td>O₂</td>
<td>6276 - 6287</td>
<td>f</td>
<td>H</td>
<td>4340</td>
</tr>
<tr>
<td>D - 1, 2</td>
<td>Na</td>
<td>5896 &amp; 5890</td>
<td>g</td>
<td>Ca</td>
<td>4227</td>
</tr>
<tr>
<td>E</td>
<td>Fe</td>
<td>5270</td>
<td>h</td>
<td>H</td>
<td>4102</td>
</tr>
<tr>
<td>b - 1, 2</td>
<td>Mg</td>
<td>5184 &amp; 5173</td>
<td>H</td>
<td>Ca</td>
<td>3968</td>
</tr>
<tr>
<td>c</td>
<td>Fe</td>
<td>4958</td>
<td>K</td>
<td>Ca</td>
<td>3934</td>
</tr>
</tbody>
</table>
"Onion" Layers of the Sun
Author’s equipment:
80 mm refractor,
Rainbow Optics Transmission Grating (200l/mm),
Nikon DSLR,
An equatorial mounting fitted with a tracking unit.

This shows the various instruments on the equatorial mounting. Left is the 80 mm refractor with the DSLR camera and grating fitted into the refractor tube where the eyepiece is currently (on the left), with the finder scope on the top. To the right is a 400 mm telephoto lens fitted with a ZWO130 CCD camera, used as a guide telescope.
number shown by the star. The 2\textsuperscript{nd} calibration point would be the
Showing the final processed image, is the spectrum of ETA Carina, with the inserted picture of the actual star. The inserted picture is only there to show what the target actually looks like.
Doug Sharpe, located in the UK, superimposed a professional spectrograph on top of the one shown above and it matches pretty well.
NOVA SGR 2015 No.2
Spectra Analyses by Amateurs
using both, commercial & homemade equipment
Locating Nova Sgr 2015 No.2

Star hop to location

1st Step – find the general area

2nd step – hop to location using detailed AAVSO map

Looking South-Southeast

2nd step – hop to location using detailed AAVSO map
Spectra photo by Percy Jacobs of Pretoria ASSA
~7.5 magnitude - 14.06.2015
Spectra photo analysed using RSPEC software
Percy Jacobs of Pretoria ASSA - ~7.5 magnitude
14.06.2015
Nova Sagittarii 2015 No. 2 14 June 15 South Africa ~mag. 7.4
Detect the Emission lines on an Emission Nebula: An emission nebula is surrounded by a gas shell that is excited (like a florescent light). Below is a spectrum of the Saturn Nebula clearing showing its emission lines. The Orion Nebula (M42) would have a similar appearance.
Detect the Red Shift of a Quasar that is 2 billion light years away. William Wiethoff’s spectra (below) of QSO 3C 273 shows the red shift due to cosmological expansion. Many amateurs capture this spectrum on 8” telescopes with less than 15 minutes integration time.
Comet spectra: This spectrum of ISON is shows how easy it is for amateurs to study astronomical spectra. Vikrant Kumar Agnihotri in India captured this wonderful spectrum of ISON using a just an 80 mm refractor, simple Star Analyser grating, and a DSLR. It clearly shows the green glow from glowing Carbon (the so-called “Swan bands” – Wikipedia link) This image was captured from a rooftop in Rajasthan, and then processed in the RSpec software:

Equipment: 80mm refractor, Star Analyser grating, Canon 1100 D. Processed using RSpec spectroscopy software
Books
Spectroscopy: The Key to the Stars – Keith Robinson
Astronomical Spectroscopy for Amateurs – Ken M. Harrison
Spectroscopic Atlas for Amateur Astronomers (no longer a free pdf download – now buy on-line through Cambridge University Press) - Version 5.0 04/2014 (if you send me an email, I can send you a pdf copy of Version 4)

Software
Tom Field - RSpec – http://www.rspec-astro.com (most preferred – software comes with video tutorials that can be downloaded)

Gratings
Rainbow Optics: manufacturer of the Star Spectroscope 200 l/mm grating - http://www.starspectroscope.com/
Paton Hawksley Star Analyser 100 (SA-100) - http://www.rspec-astro.com/star-analyser/

Groups
Astronomical Spectroscopy for Amateurs
https://groups.yahoo.com/neo/groups/RSpec_Real_Time_Spectroscopy/info

Basic Astronomical Spectroscopy Software
https://uk.groups.yahoo.com/neo/groups/astrobodger/info

Ken M. Harrison – very specialised in amateur spectroscopy and willing to help – ex member of the Durban ASSA group – you can contact him via the above “yahoo” group or direct on kenm.Harrison@gmail.com

Robin Leadbeater - THREE HILLS OBSERVATORY - (Formerly "ROBIN'S ASTRONOMY PAGE")
http://www.threehillsobservatory.co.uk/astro/astro.htm

A Good List of Links
http://www.stargazing.net/david/spectroscopy/links.html

Astronomical Society of Southern Africa
http://assa.saao.ac.za/sections/photometry-spectroscopy/spectroscopy/
Thank You