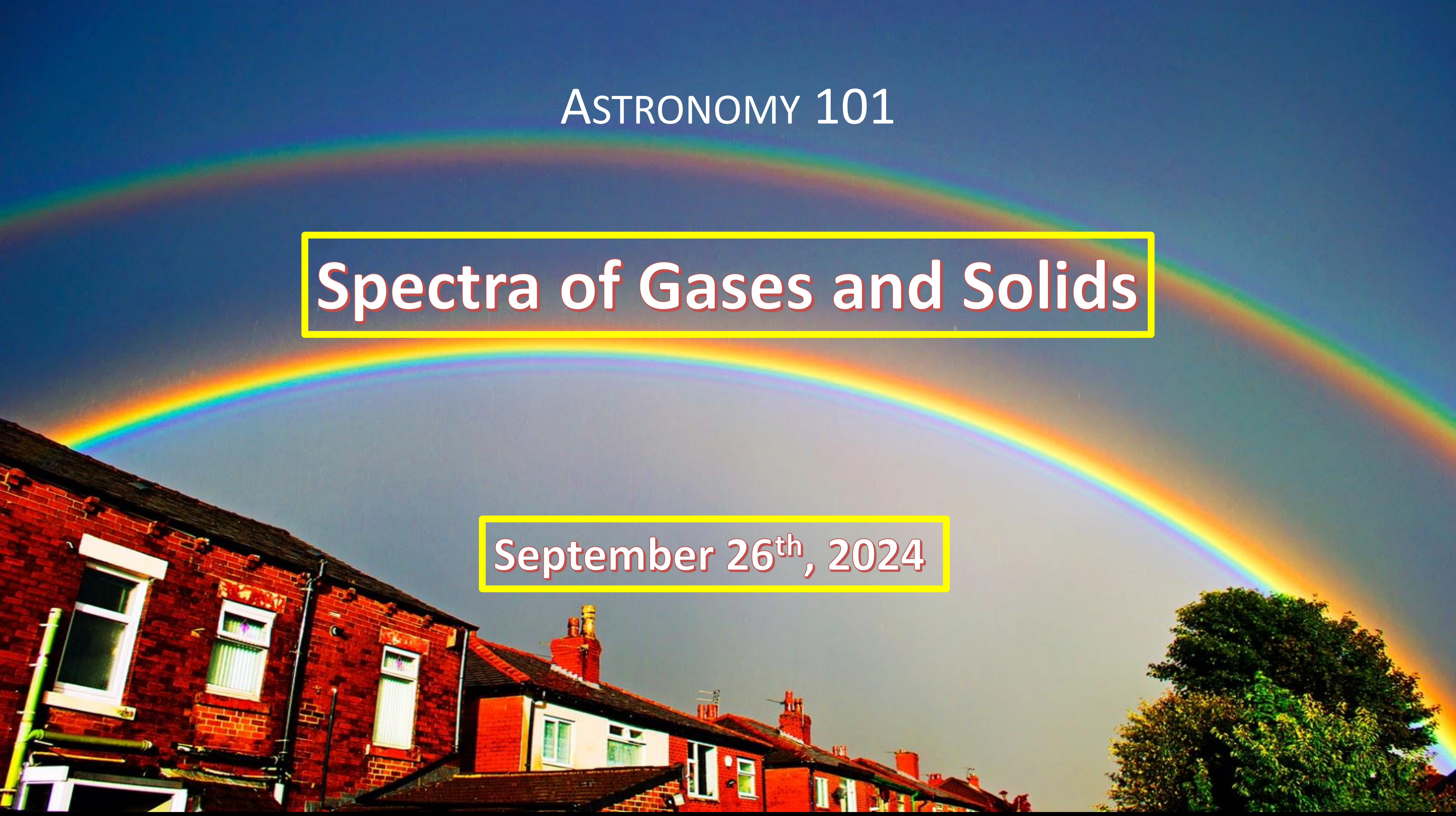
ASTRONOMY 101

Spectra of Gases and Solids

September 26th, 2024



Housekeeping

Lab Rubric, GIMP installation and usage instructions, Spectra images and Submission Portal are on Brightspace

Labs are due October 3rd at 11:59 PM

Housekeeping Continued

Attendance at Labs is <u>Mandatory!</u>

Lab Recordings will be posted on Brightspace for your reference but are not meant as a substitute for class attendance

Late Labs are generally not accepted, please email me if you need an extension for a valid unforeseen reason such as illness or a family emergency

Please Review the Lab Report Expectations in the Lab Manual

Lab Report Overview

Objective/Introduction: One or two sentences for the objective stating the goal(s) of the lab.

The Introduction should be several paragraphs (at least half a page) discussing the scientific concepts of the lab, including any relevant historical context may be included but should not comprise most of the introduction

Procedure: Short paragraph walking through the procedure or steps of the lab.

Observations/Tables/Graphs: All tables, graphs and sketches will go in this section.

Calculations: Sample calculations for each equation used will go in this section

Answers: Answer the the questions in the lab manual in this section.

Lab Report Overview Continued

Discussion:
Arguably the most important section of the lab report, so please do not skip this section!
The discussion should be several paragraphs long (unless otherwise stated) discussing your results and summarizing the following
Did you meet the objective?

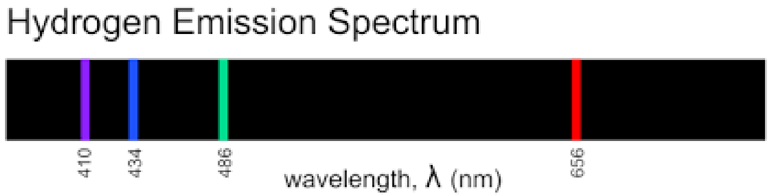
- **Why or why not?**
- **Were any assumptions made that may affect your results?**
- **What are the sources of error if any?**
- **What is the broader context?**

Conclusions/References: A short paragraph restating your results where you cite any references used in your lab report (You're expected to use
outside sources for each lab). Please also include in text citations as well.

Spectra Lab
Learning Objectives

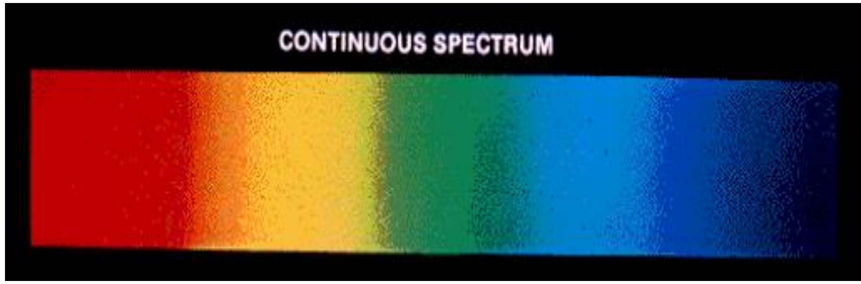
- Nature of light → electromagnetic radiation
- Generation of a spectrum
- Types of spectra (continuum, absorption and emission)
- Measurement of wavelengths of atomic spectral lines
- Identification of an unknown element by its spectrum

Spectroscopy - the study of the interaction between matter and electromagnetic radiation

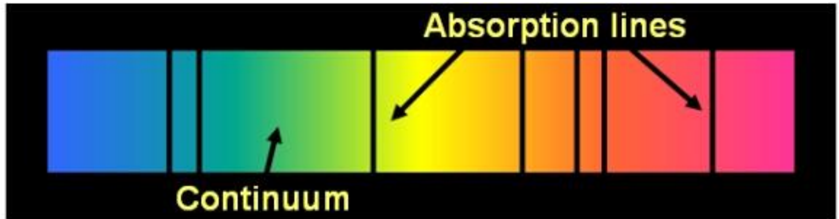


From spectral lines astronomers can determine:

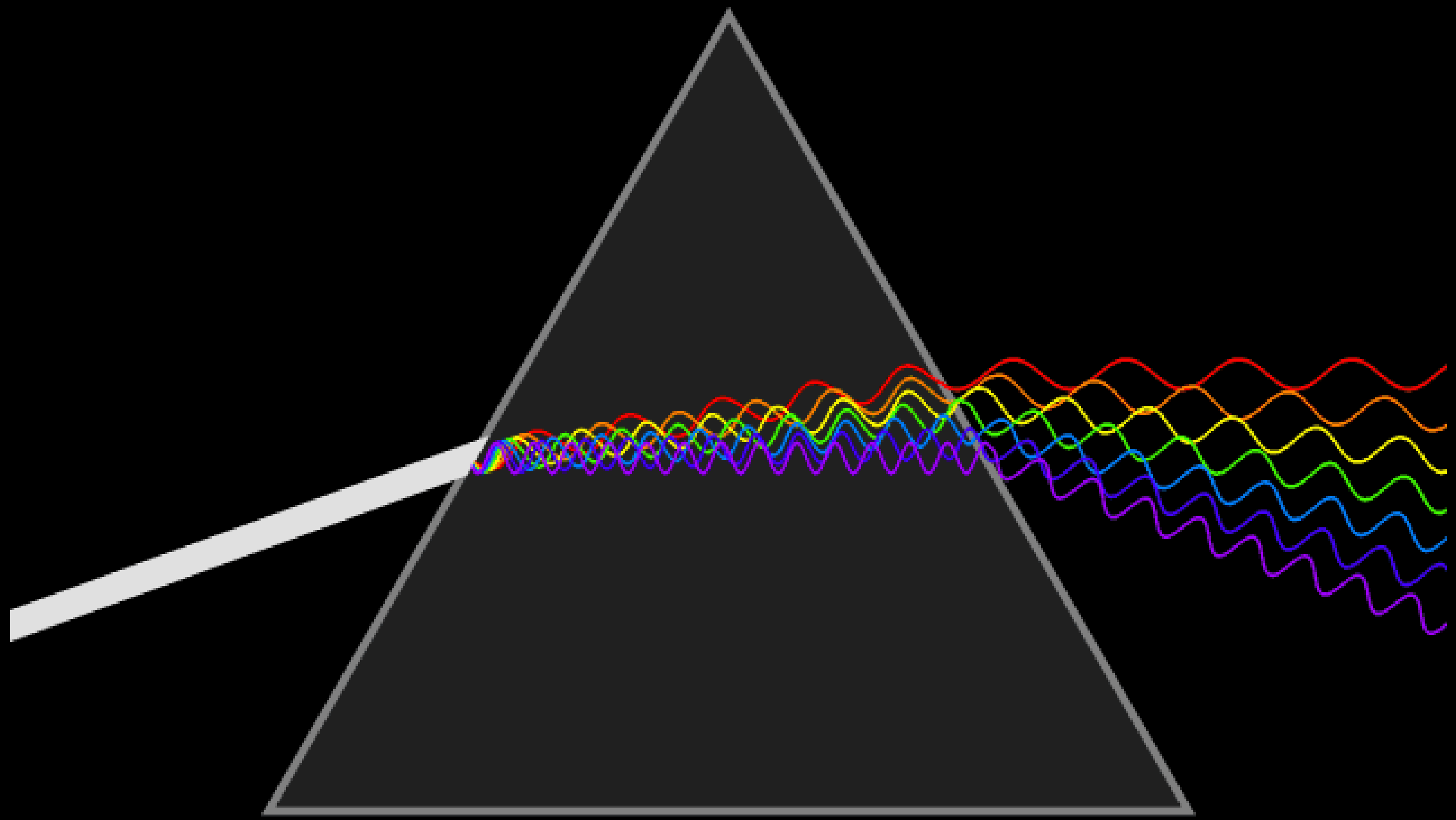
- the presence and density of an element
- temperature from the wavelength distribution of the continuum (Wein's Law)
  - add luminosity to get the mass and size
- internal temperature from spectral line width
- the magnetic field from line splitting and polarization
- stellar winds from x-ray emissions
- orbital period and velocity from line movement over time (Doppler Shift)
- the physical changes in the star from line intensity changes over time
- the material around stars - the interstellar medium (ISM).



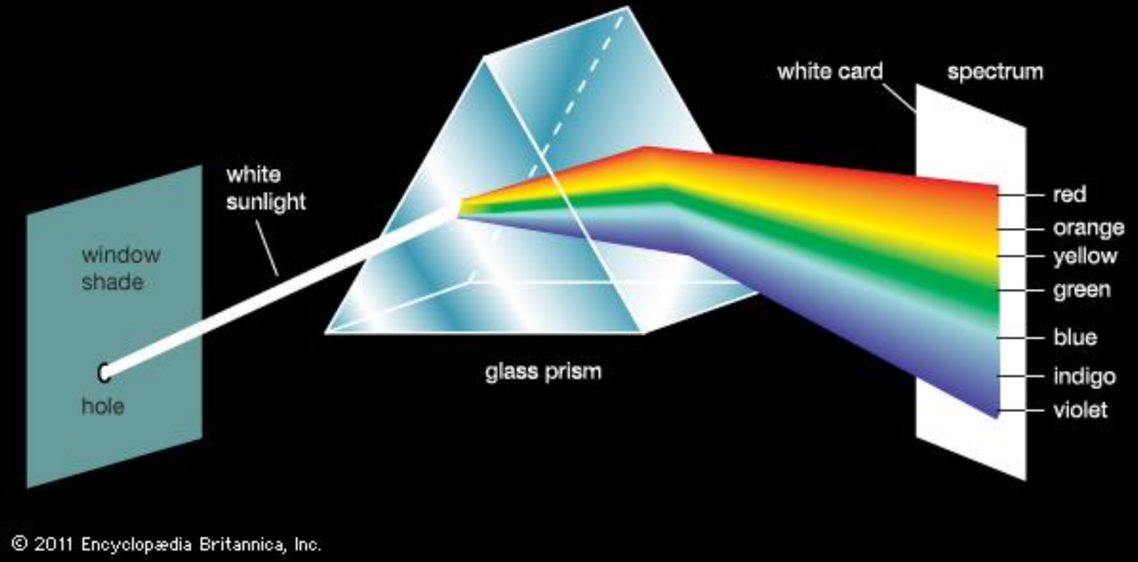
Spectroscopy is a fundamental tool used to study the universe.



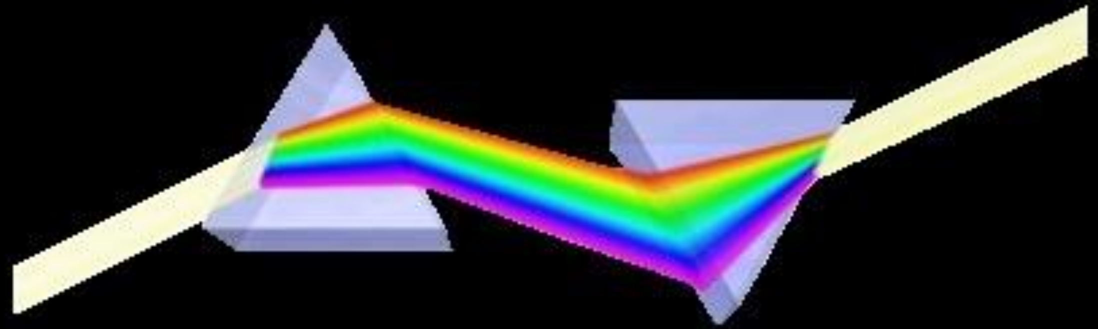
Light Refraction Through a Prism



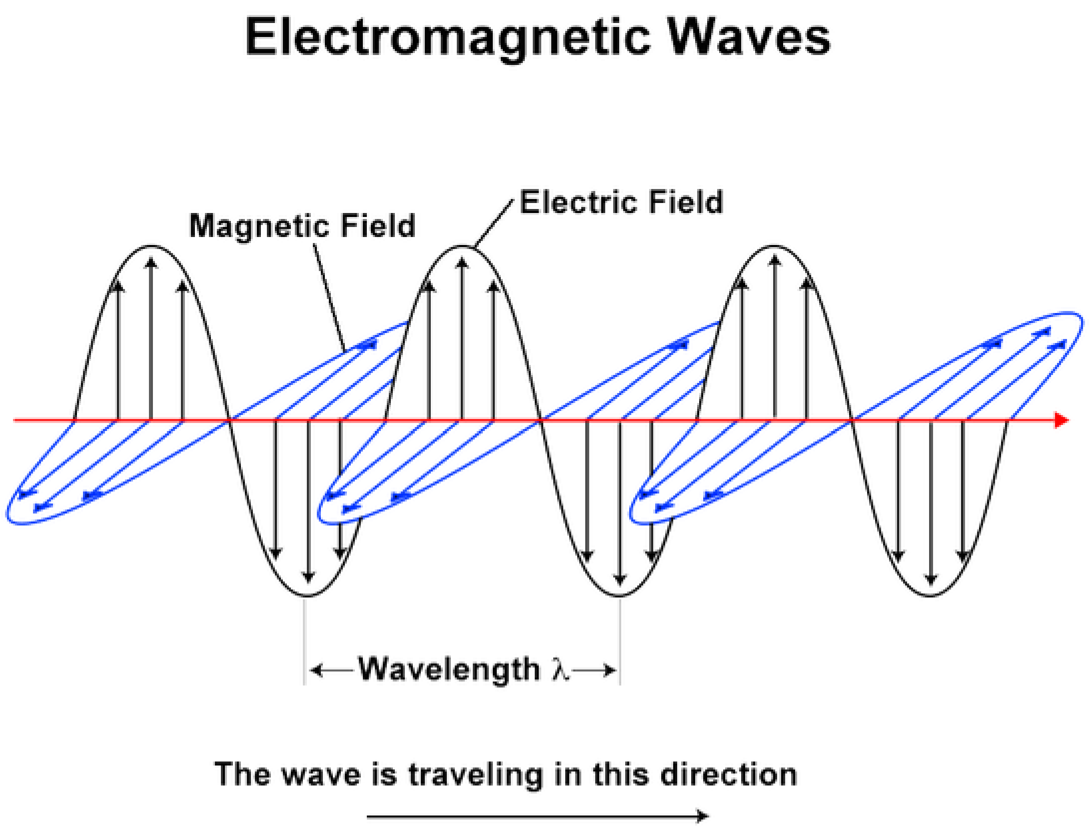
Prisms



In 1666, Sir Isaac Newton passed a beam of sunlight through a glass prism producing the visible colour spectrum on a wall.



He then projected light through a second prism to create white light.
Conclusion: the colour spectrum projected is the result of the prism interacting with already-coloured light rather than prism itself generating the colour.

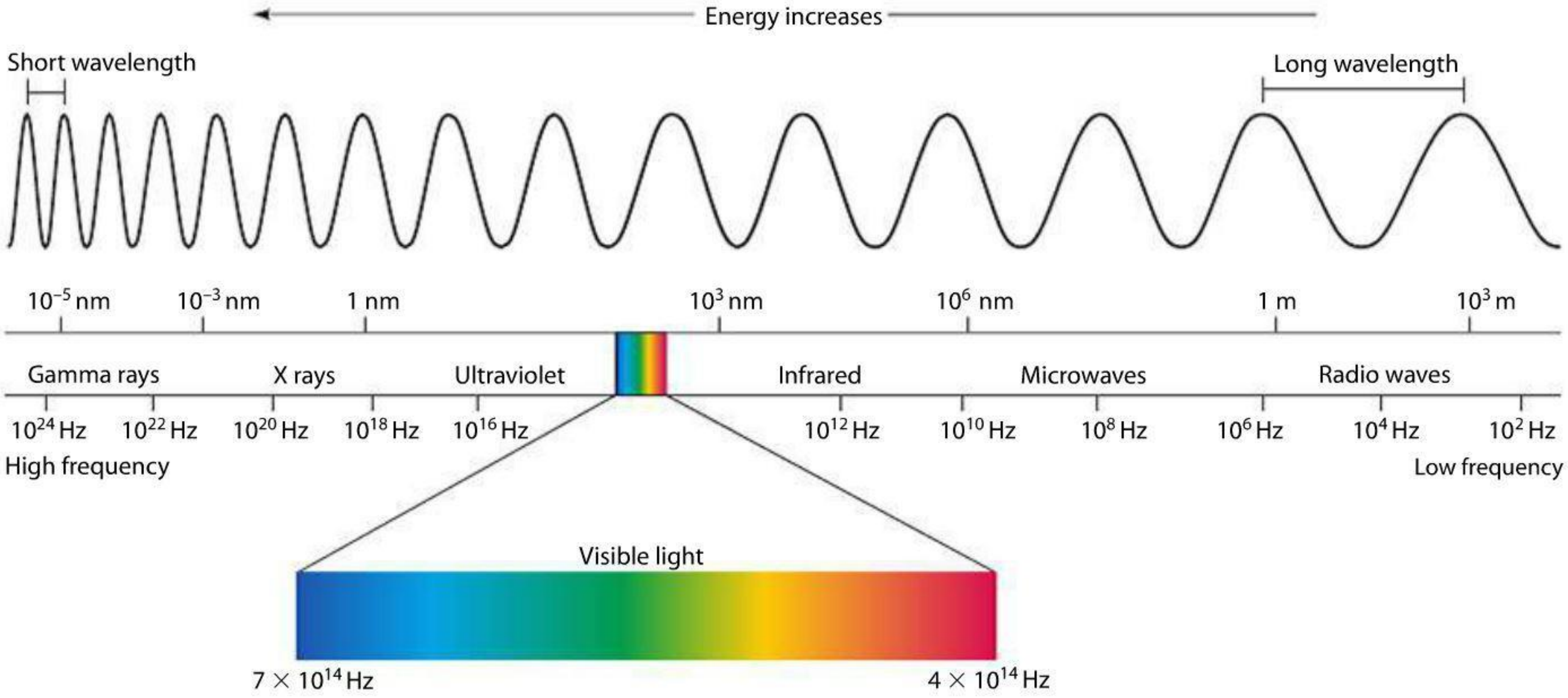


A Few Light Facts

Light waves:

- are transverse electromagnetic waves
- carry energy
- are emitted and absorbed by matter
- travel at 300 000 km/s in a vacuum and slower in a more dense medium
- can be reflected and refracted
- travel through a vacuum and some matter

The Electromagnetic Spectrum



4000 Å = 400 nm

7000 Å = 700 nm

velocity = frequency x wavelength = 299 792.458 km/s (speed of light in a vacuum)

$\sim 300\ 000\ \mathrm{km/s}$

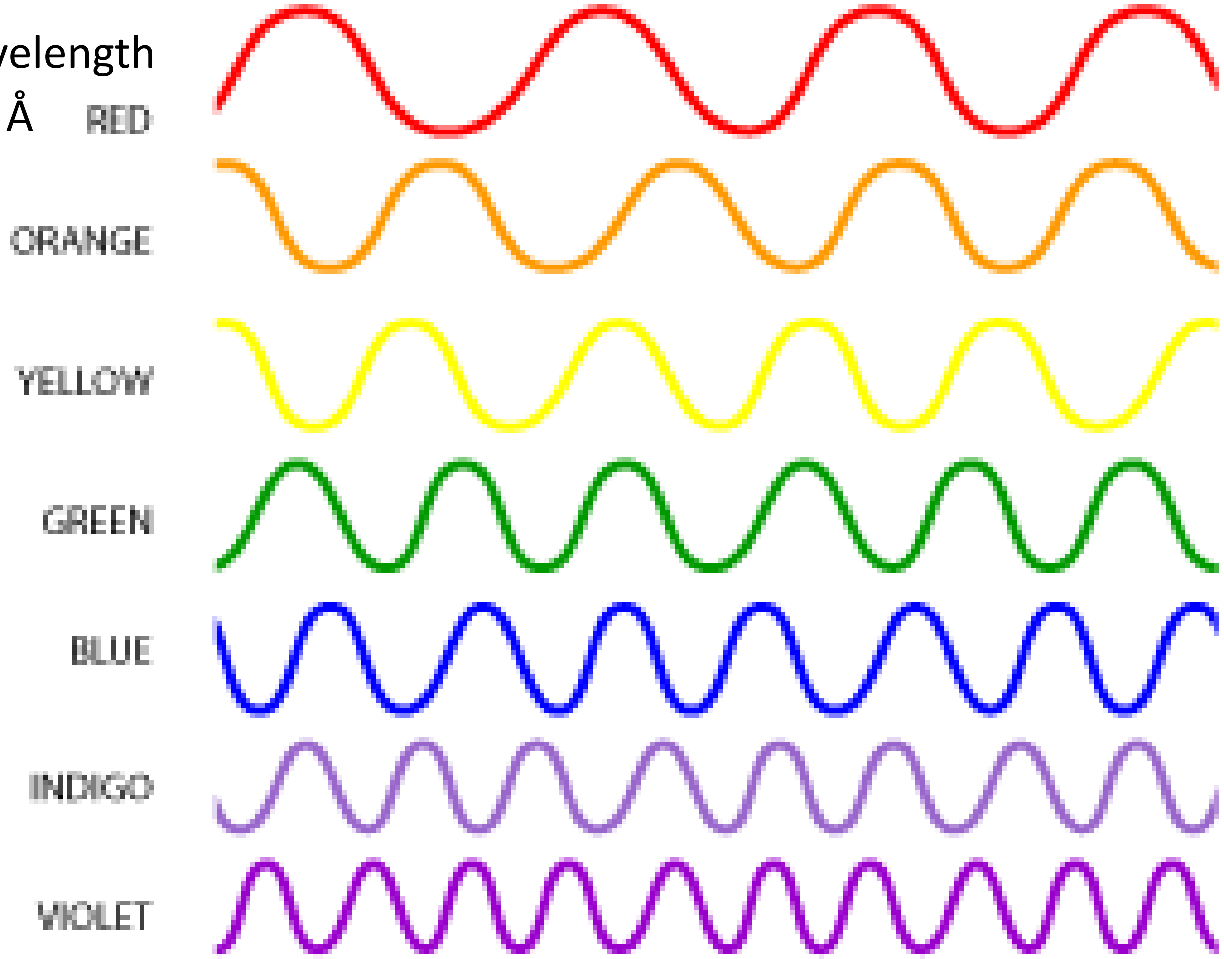
The Visible Spectrum

Longer wavelength

~ 7000 Å

Lower frequency

Lower energy



~ 4000 Å

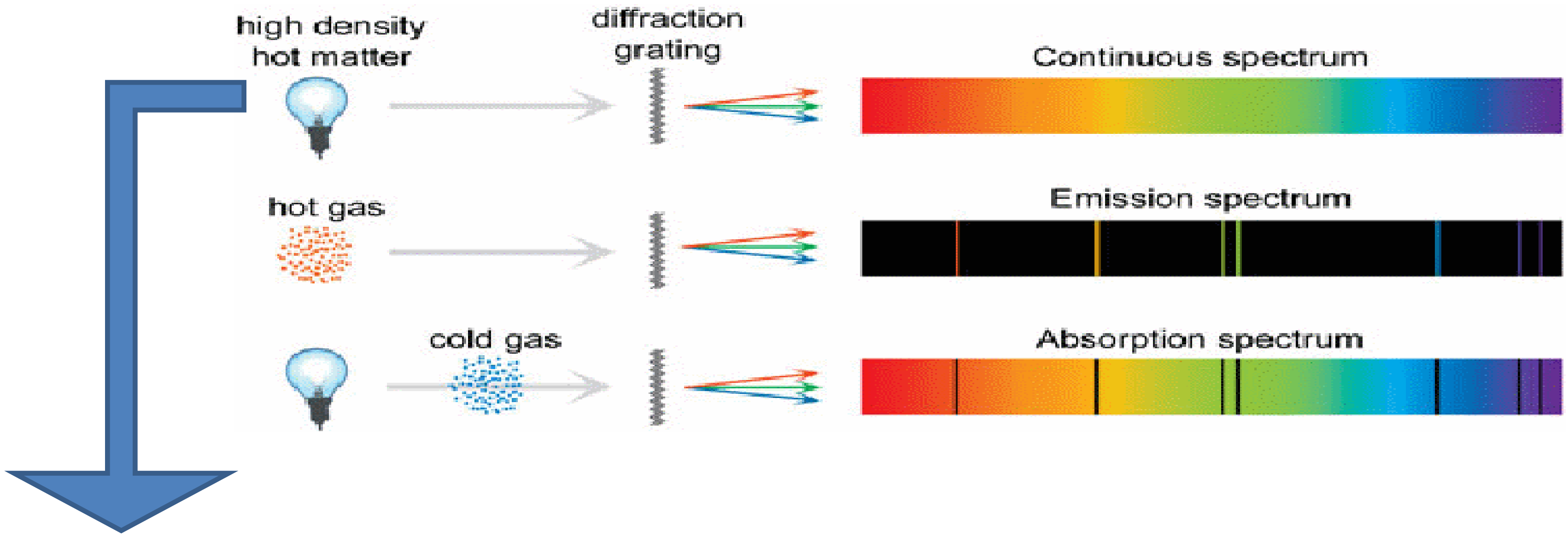
Shorter wavelength

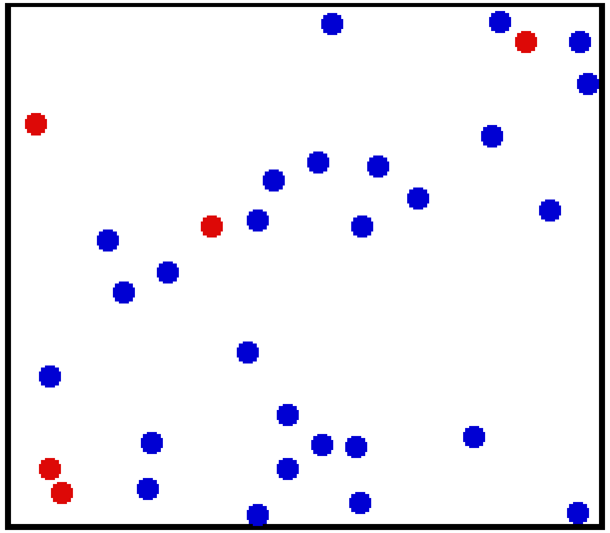
Higher frequency

Higher energy

The **Ångström** (Å) is a unit of length equal to 10^{-10} m (one ten-billionth of a metre) named after the Swedish physicist Anders Jonas Ångström (1814–1874).

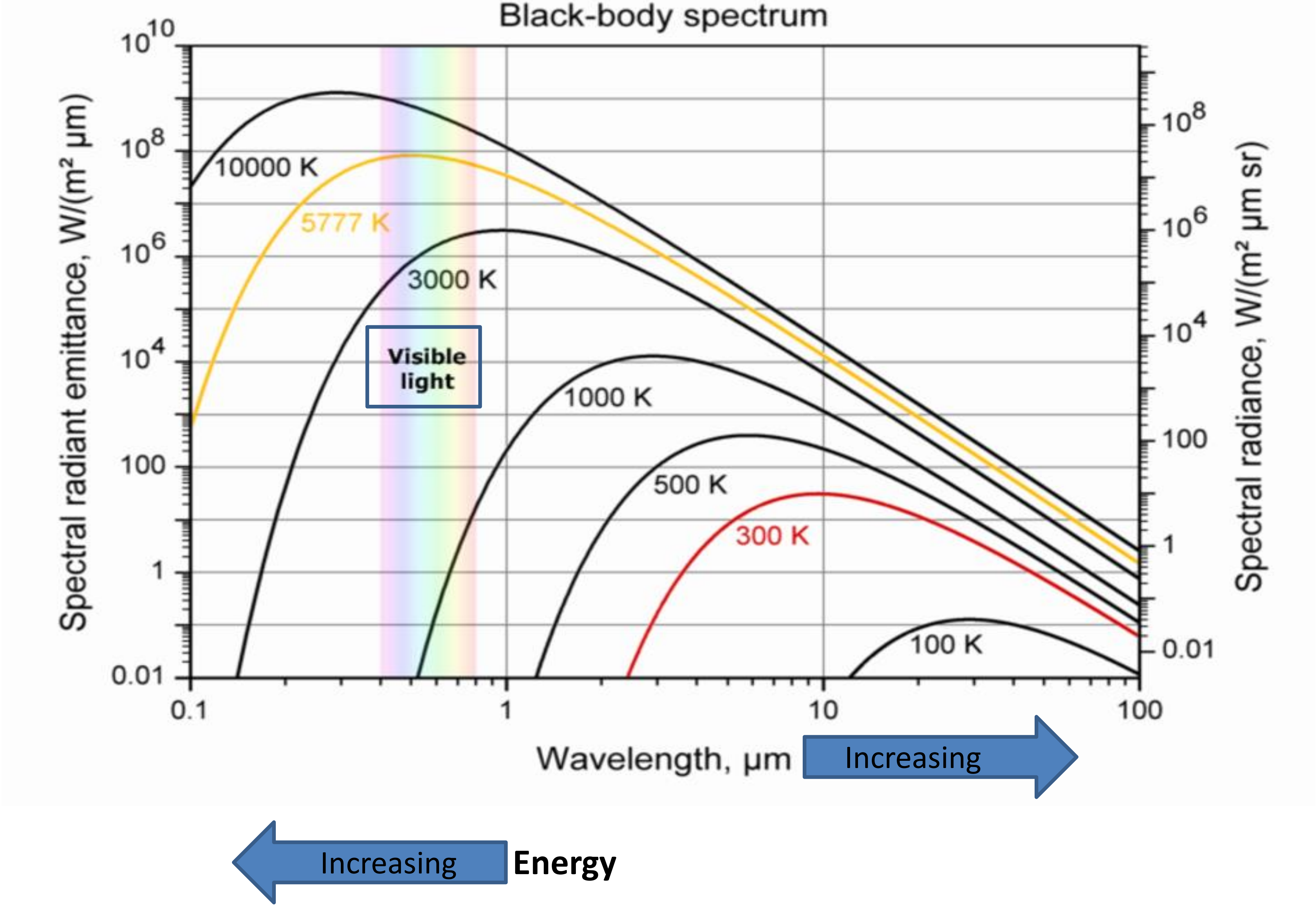
Emission and Absorption Spectra

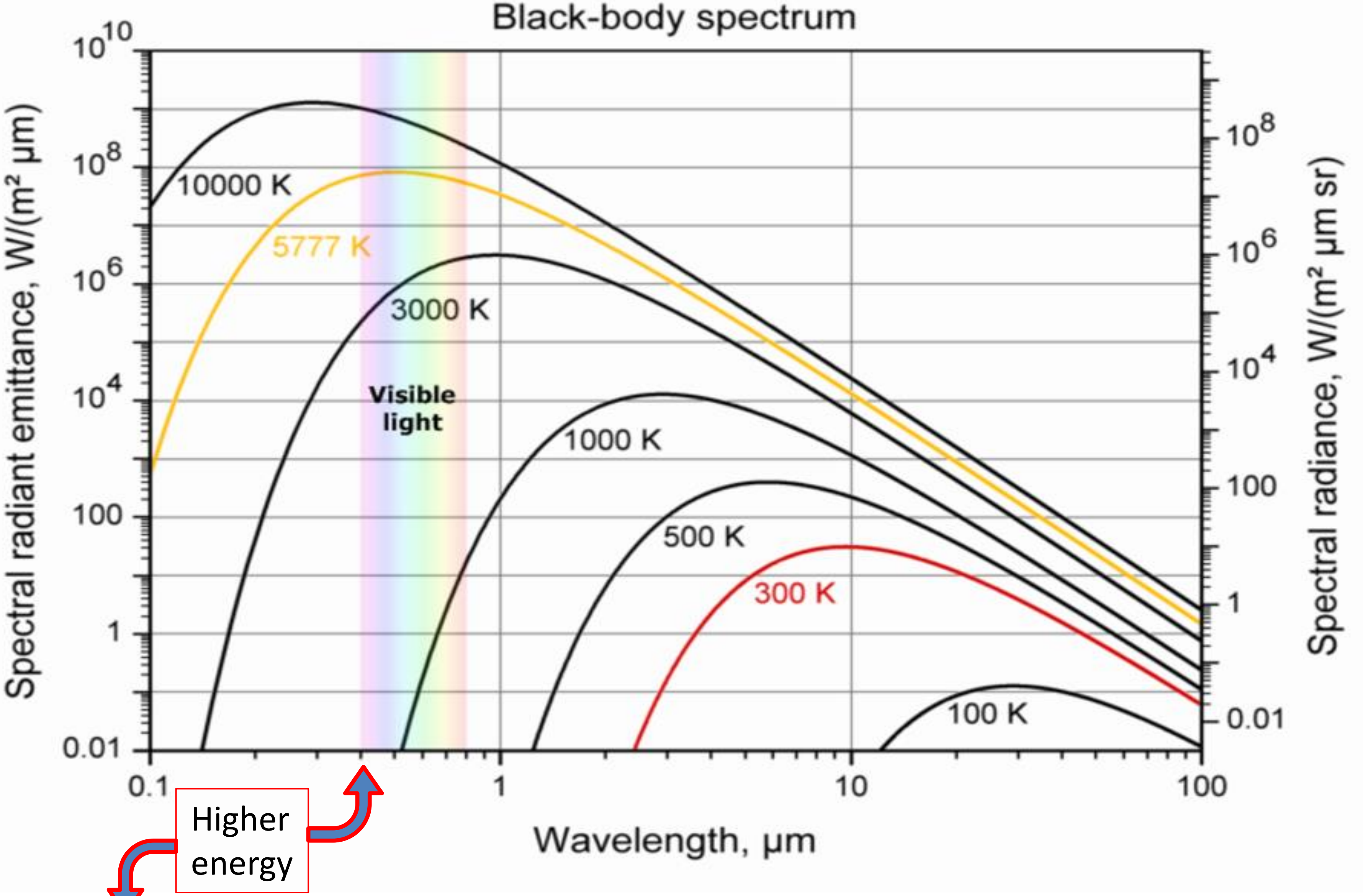


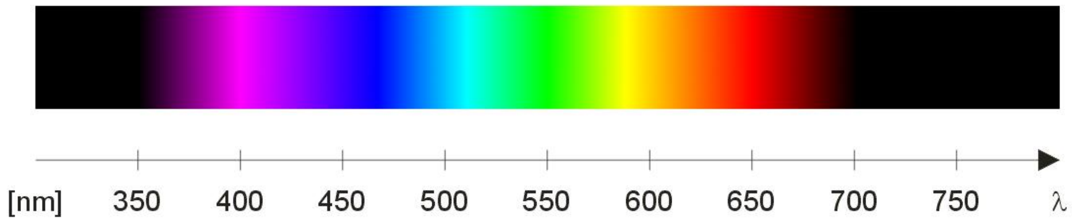


Continuous spectrum is produced by hot, dense objects

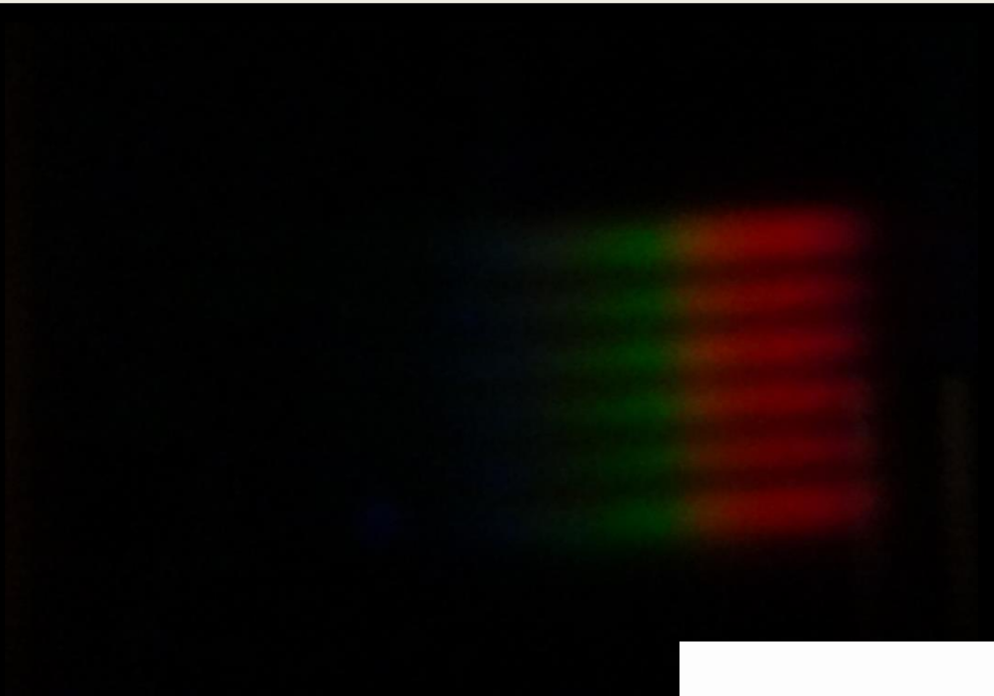
- heated metal, a star, humans, ice cubes and all matter > 0 K
- caused by internal motion and collisions of the particles (*temperature*)

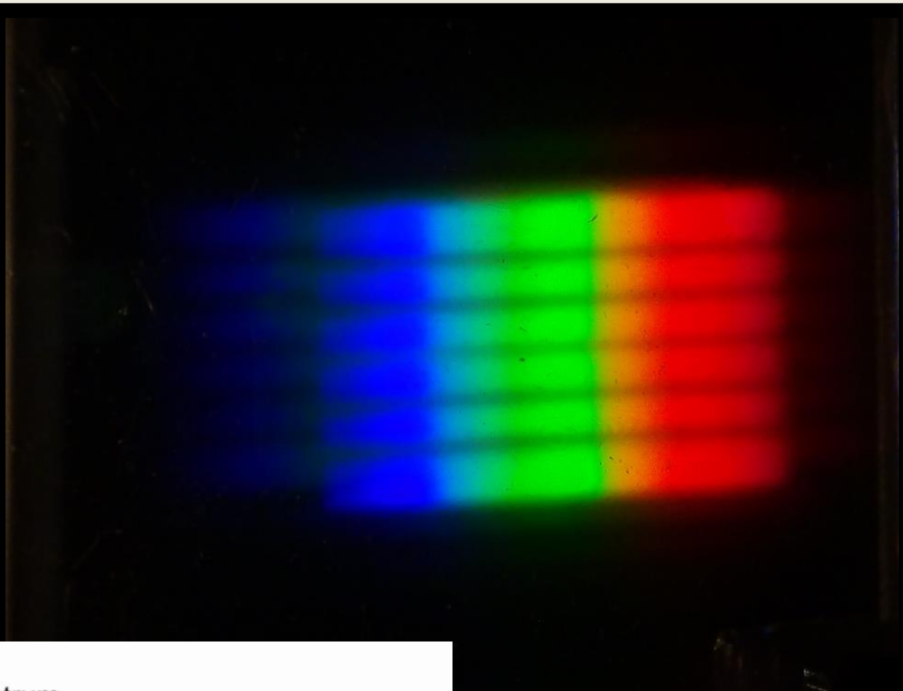

Black-body spectrum
Spectral radiant emittance, W/(m² μm)
Spectral radiance, W/(m² μm sr)
10000 K
5777 K
3000 K
1000 K
500 K
300 K
100 K
Visible light
0.1
1
10
100
Wavelength, μm
Increasing
Increasing
Energy


Black-body spectrum
Spectral radiant emittance, W/(m² μm)
Spectral radiance, W/(m² μm sr)
Wavelength, μm
10000 K
5777 K
3000 K
1000 K
500 K
300 K
100 K
Visible light
Higher energy
0.1
1
10
100
0.01
1
100
10^4
10^6
10^8
10^10

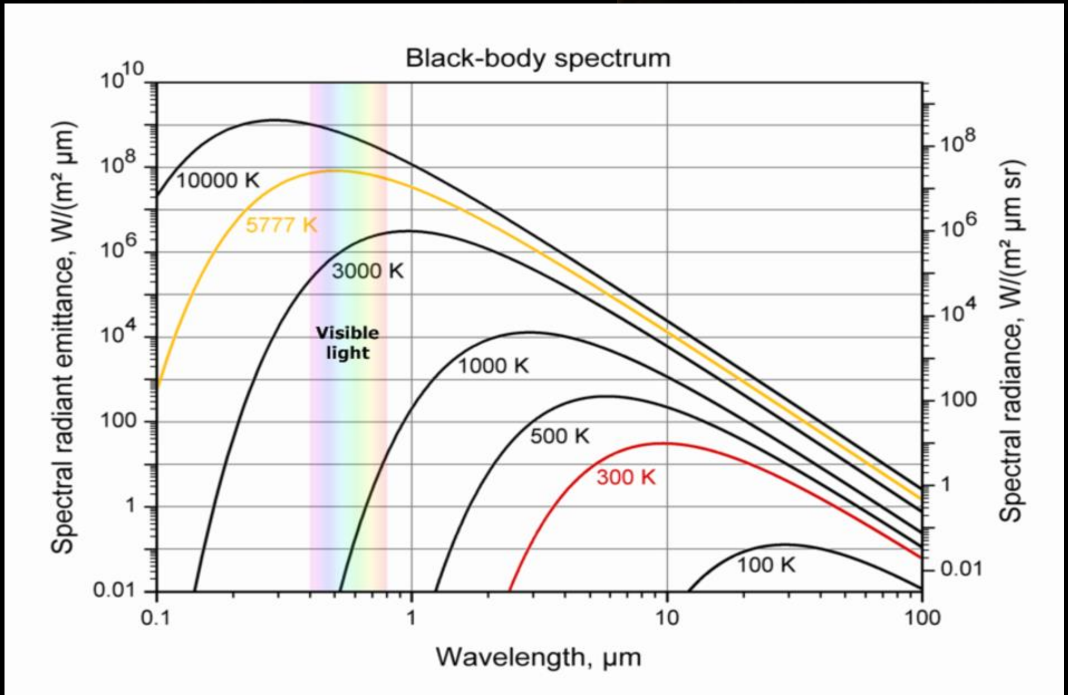

[nm]
350
400
450
500
550
600
650
700
750
λ

Incandescent Spectrum



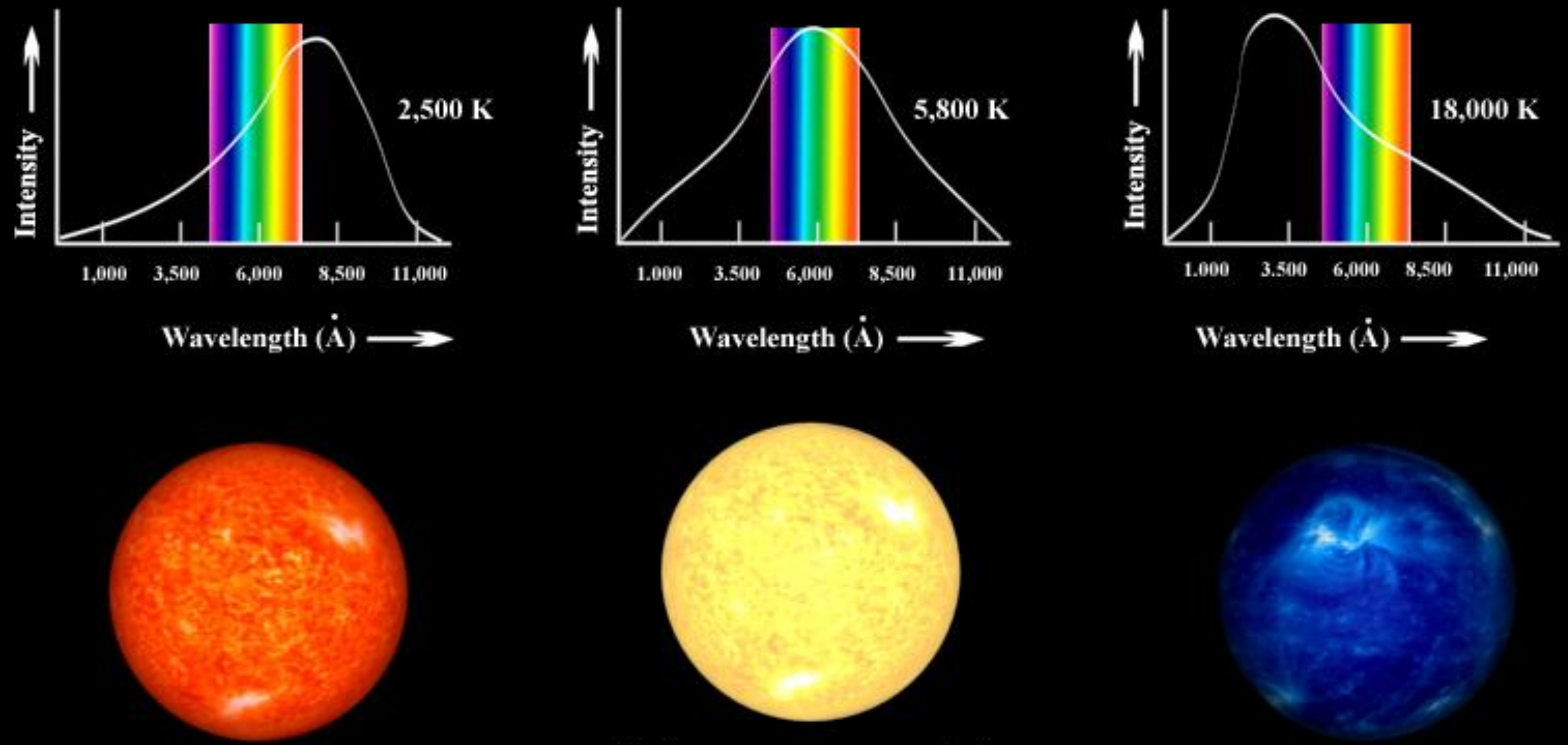


Cool tungsten filament
T ≈ 1000 K



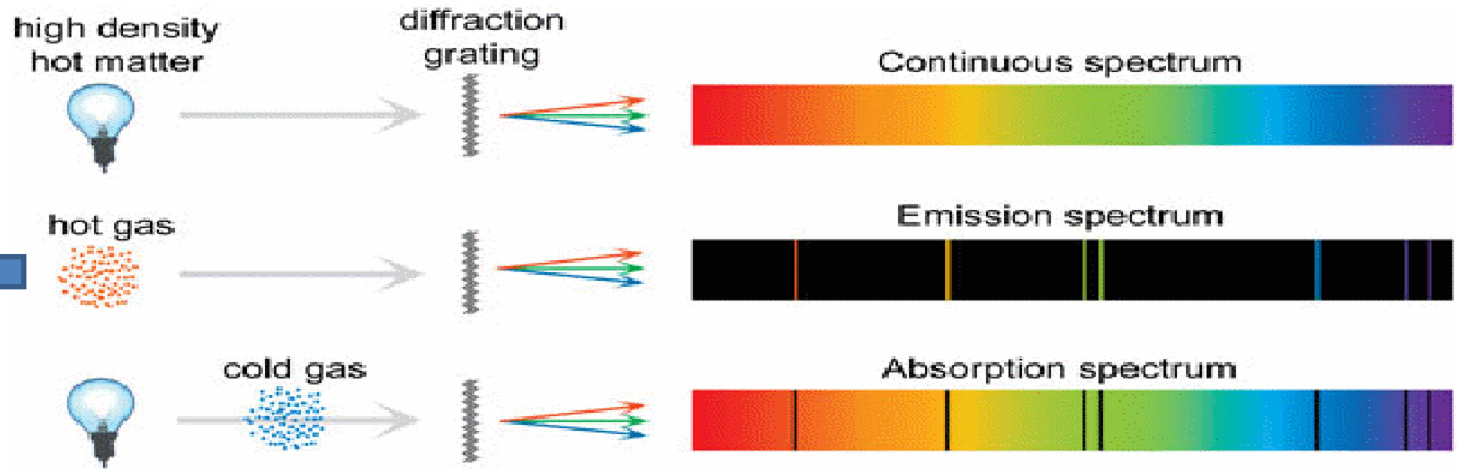
Hot tungsten filament
T ≈ 2800 K (melts at 3695 K)

Star Temperature and Colour

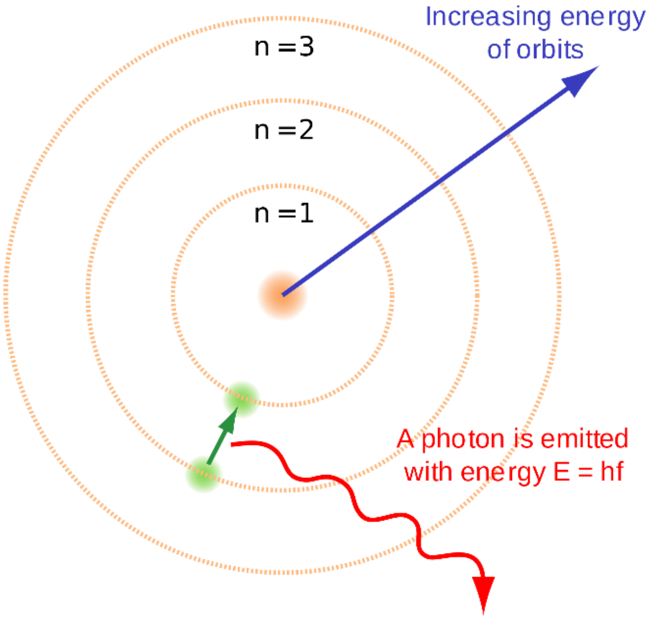


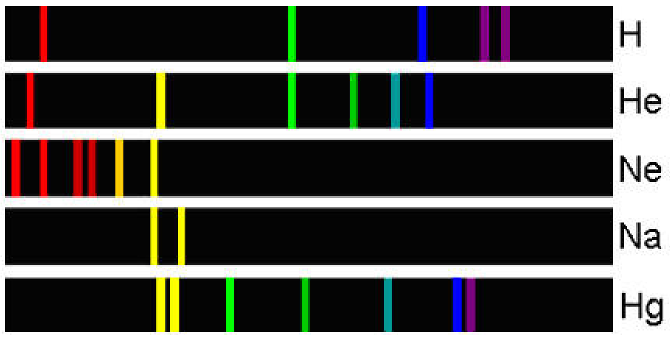
Colors are exagerrated

Emission and Absorption Spectra

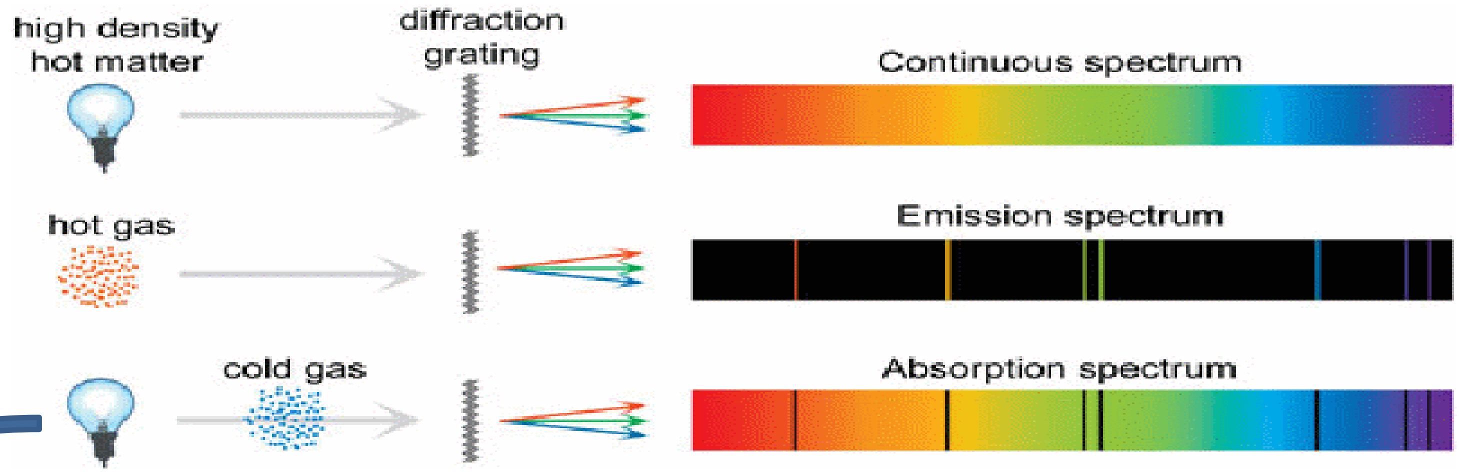


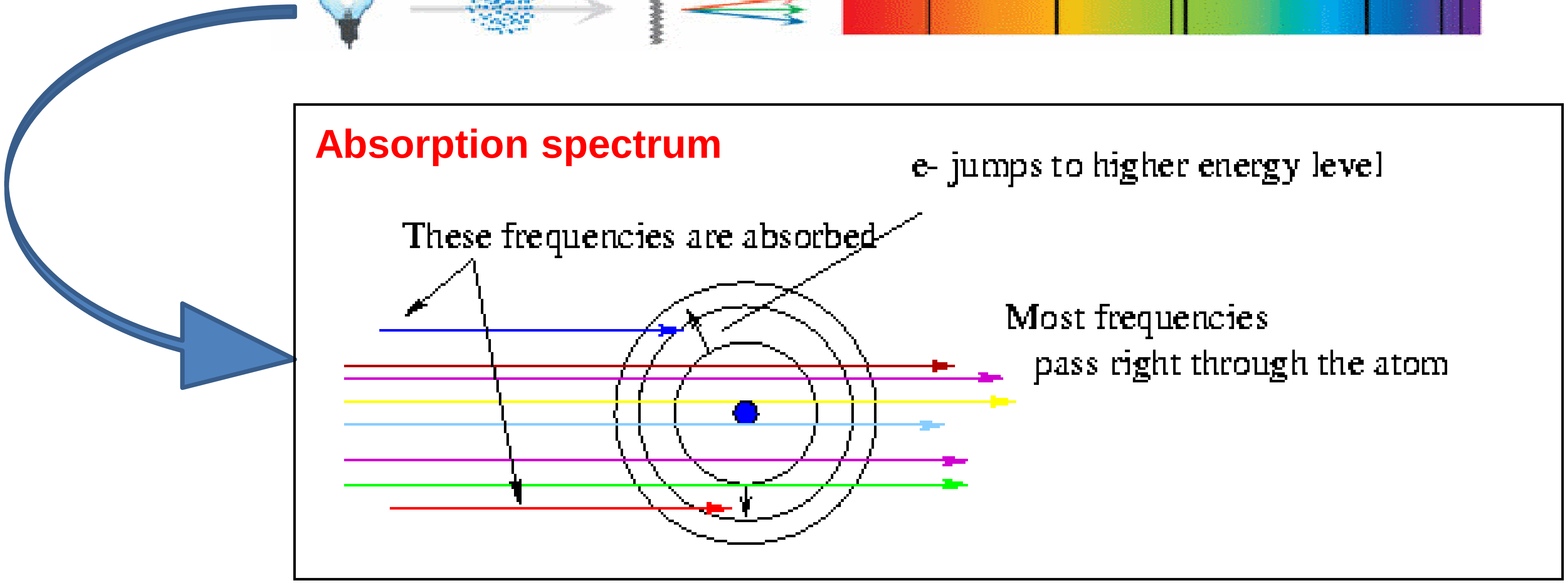
Emission spectrum occurs when the electrons of an excited atom, element or molecule move to lower energy levels.



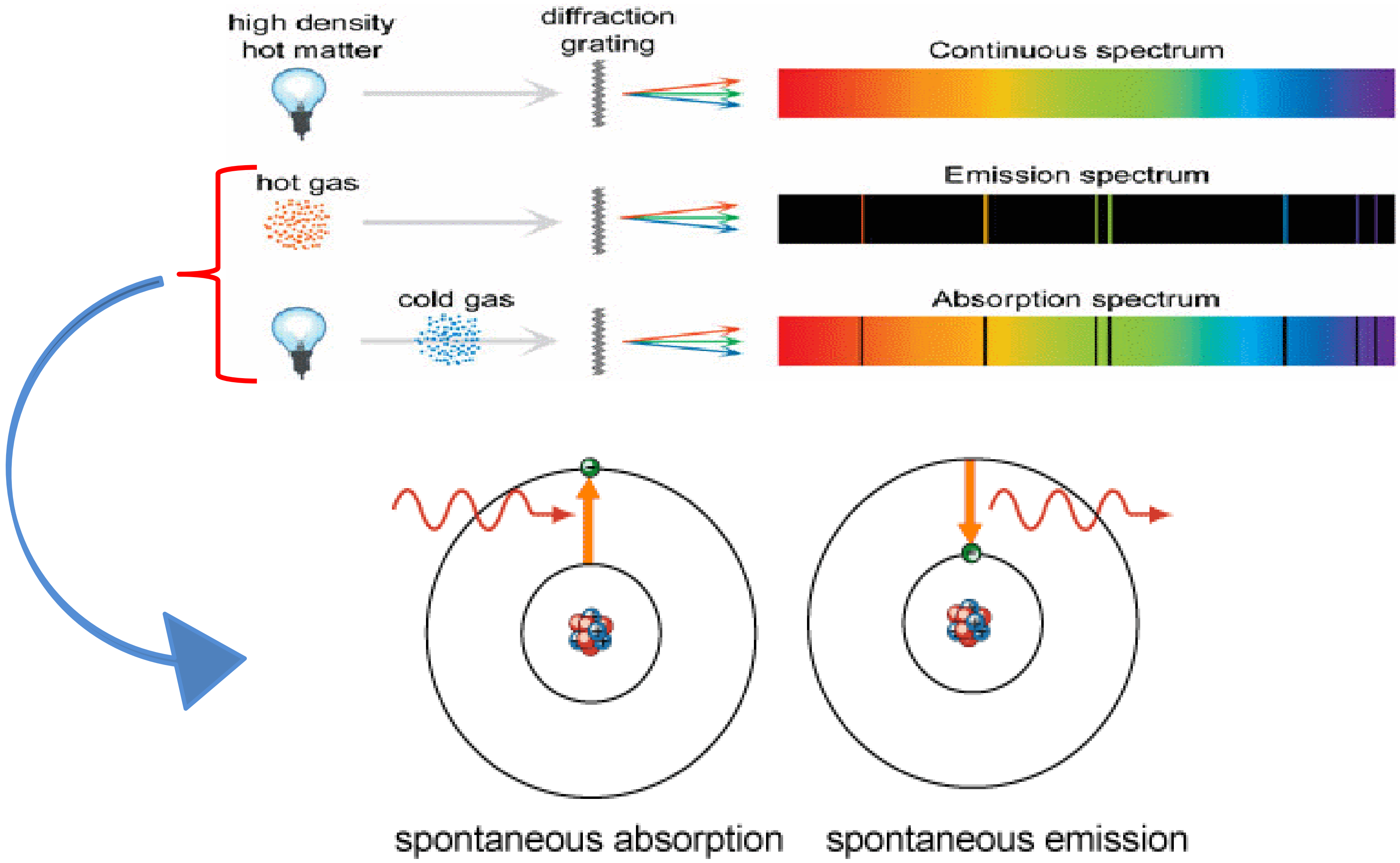


Emission and Absorption Spectra

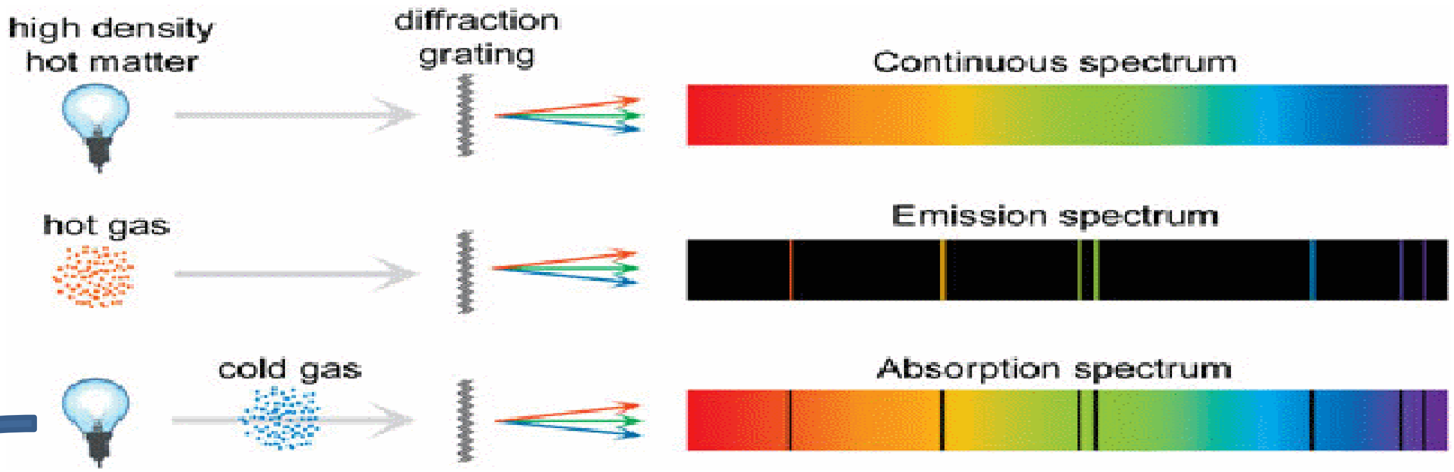


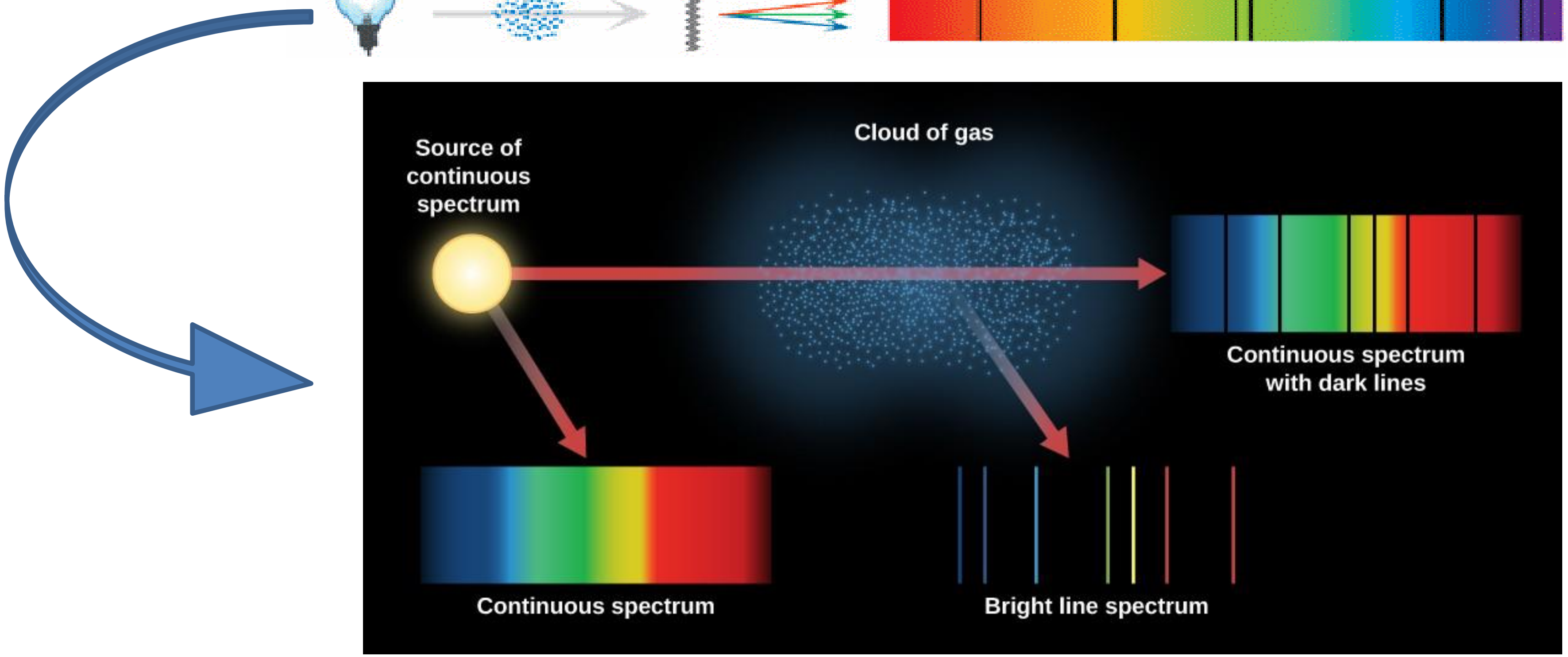


Emission and Absorption Spectra

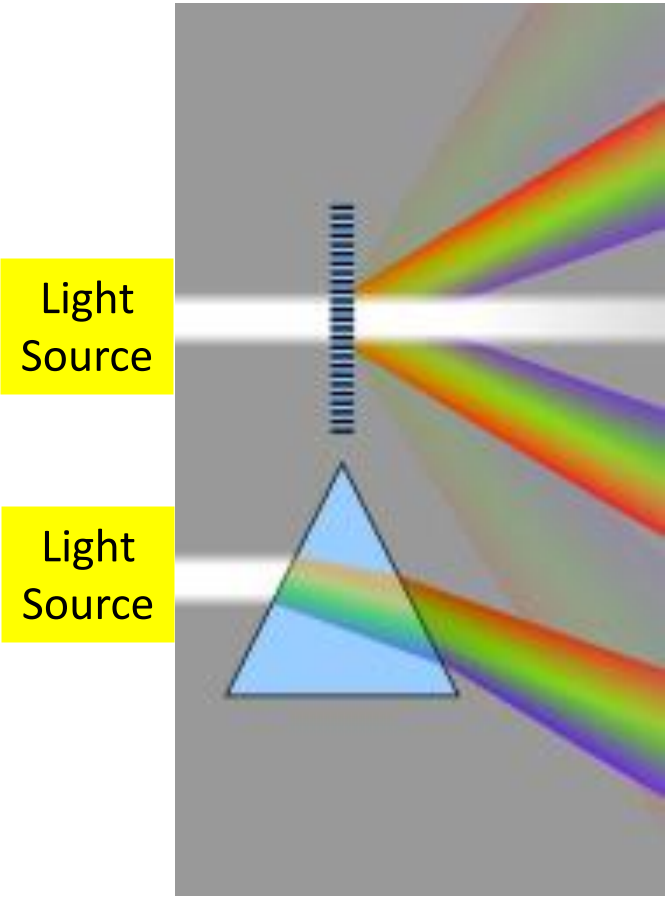


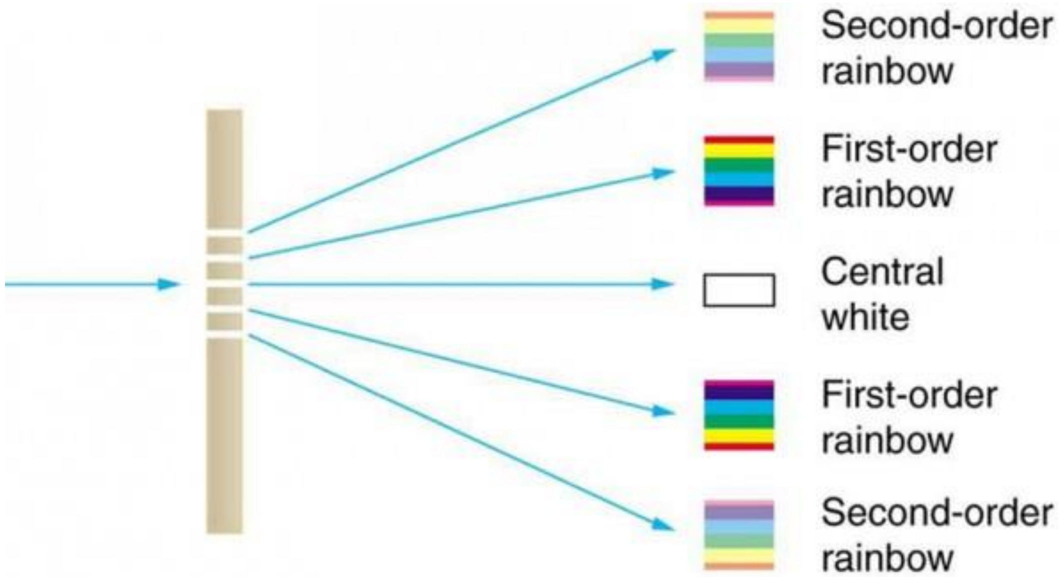
Emission and Absorption Spectra

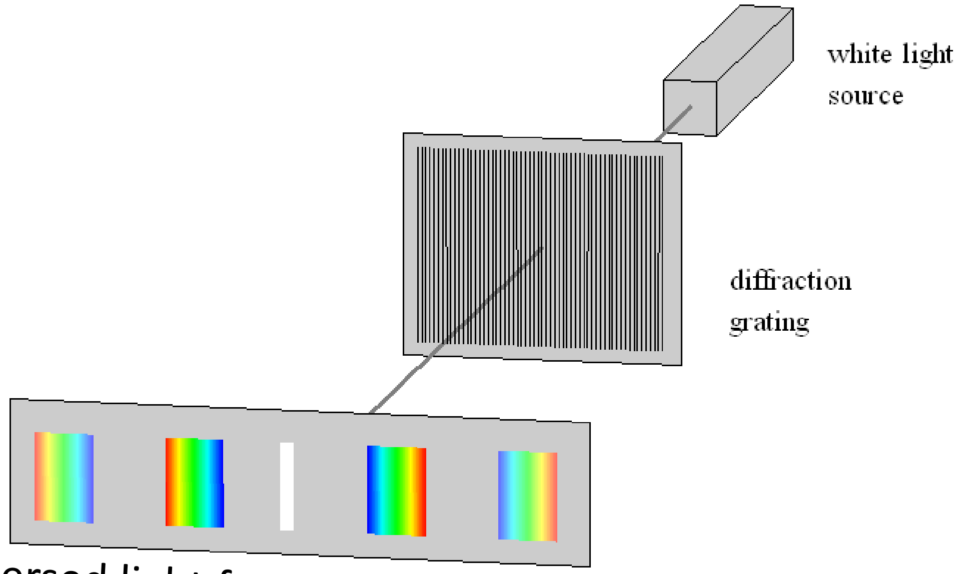




Gratings and Prisms





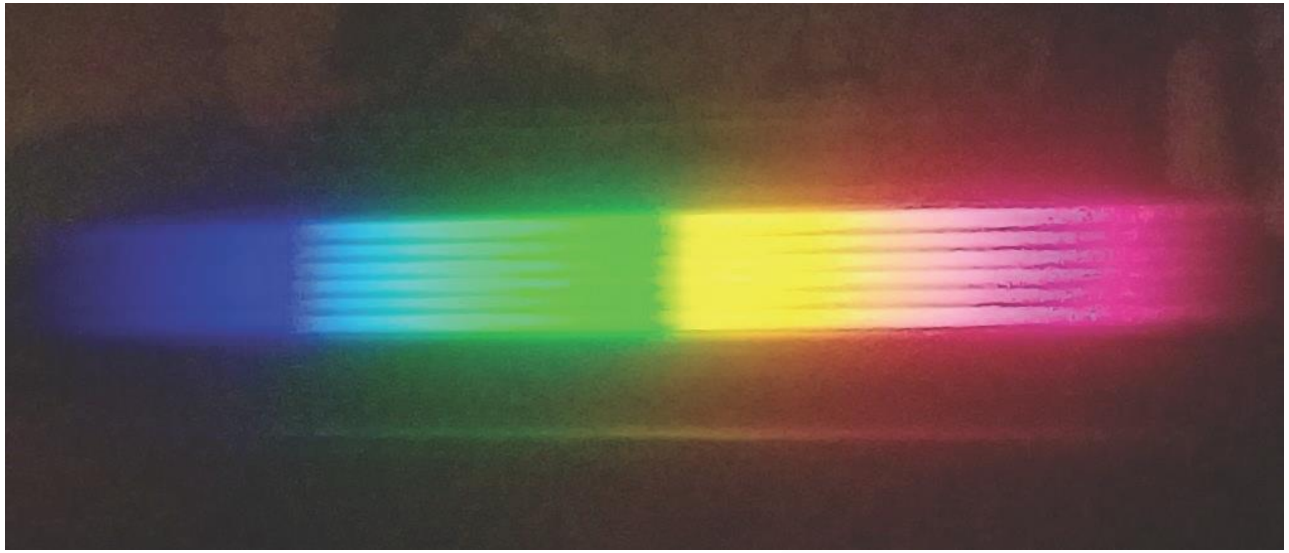


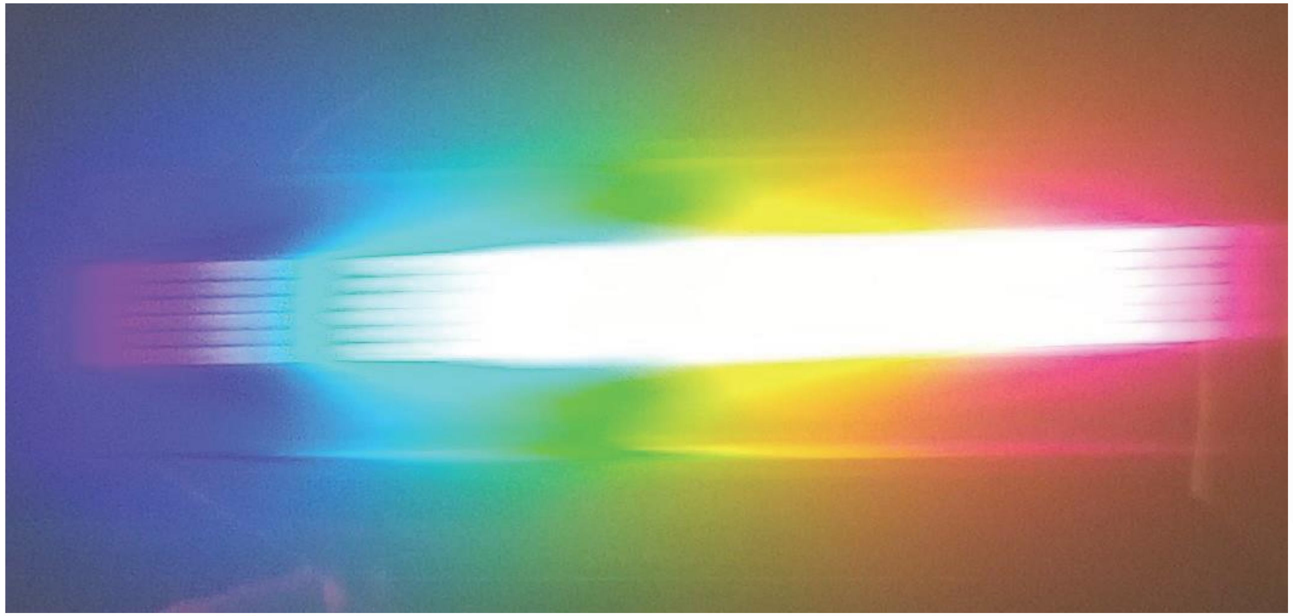
Dispersed light from diffraction grating

PART I: VISUAL OBSERVATION OF DIFFERENT TYPES OF SPECTRA.

- At the front of the lab, there are several different light sources. You will need to sketch & describe the spectra of each one.
- Focus on the prominent lines and their approximate spacing/brightness
- We will allow you to take photos. HOWEVER, there are some things you need to be careful of:
  - You need to make sure you actually photographed the spectrum you're interested in and not one from a nearby source
  - It's quite easy for the sensor on your camera to be saturated by bright sources. In order to get the necessary detail it may be best to sketch
  - The camera may have a hard time picking up any lines present in the solar spectrum

Source 1: Incandescent Bulb Spectra





The horizontal lines in the spectrum are from the bulb supports, they aren't absorption lines.

Take a picture of the spectrum at **low** and **high** power.

Where is it **brightest** (most intense) in each case?

Describe the spectra. What kind of spectra are they?

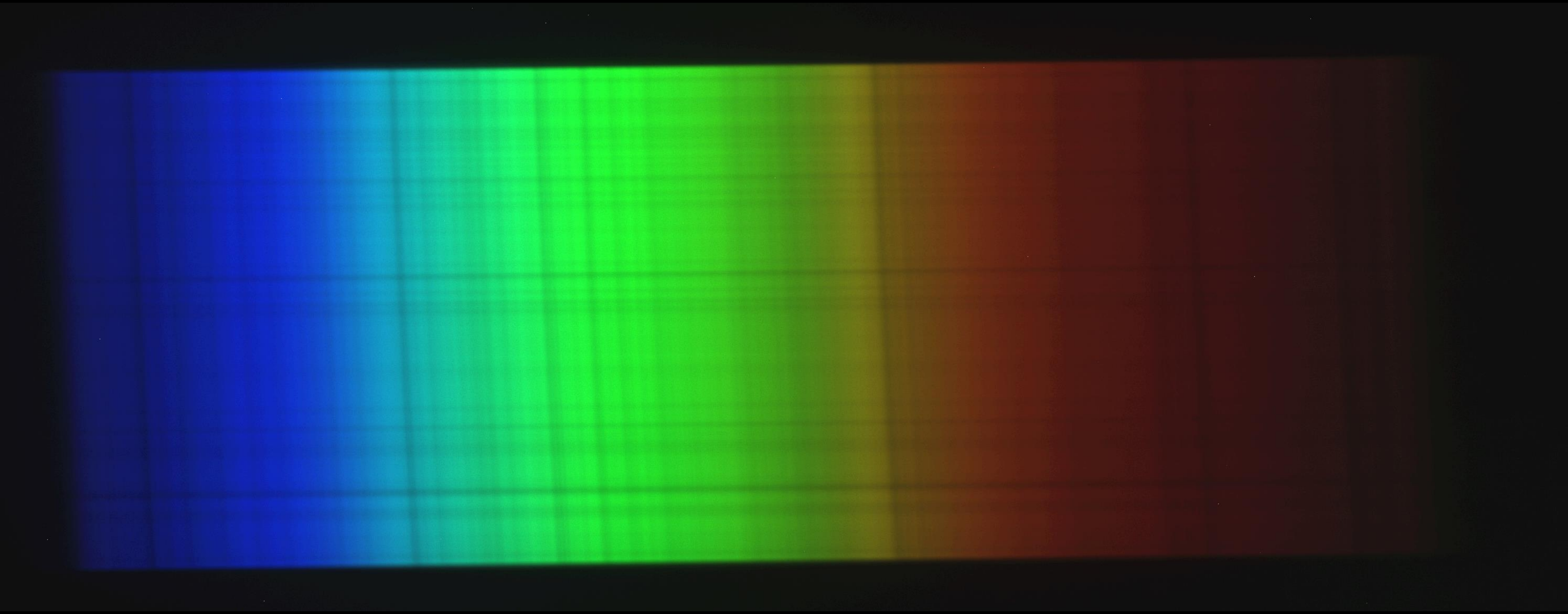
Source 2: Fluorescent Tube Spectrum

Fluorescent Lights are phosphor-coated tubes filled by low-density Mercury vapour

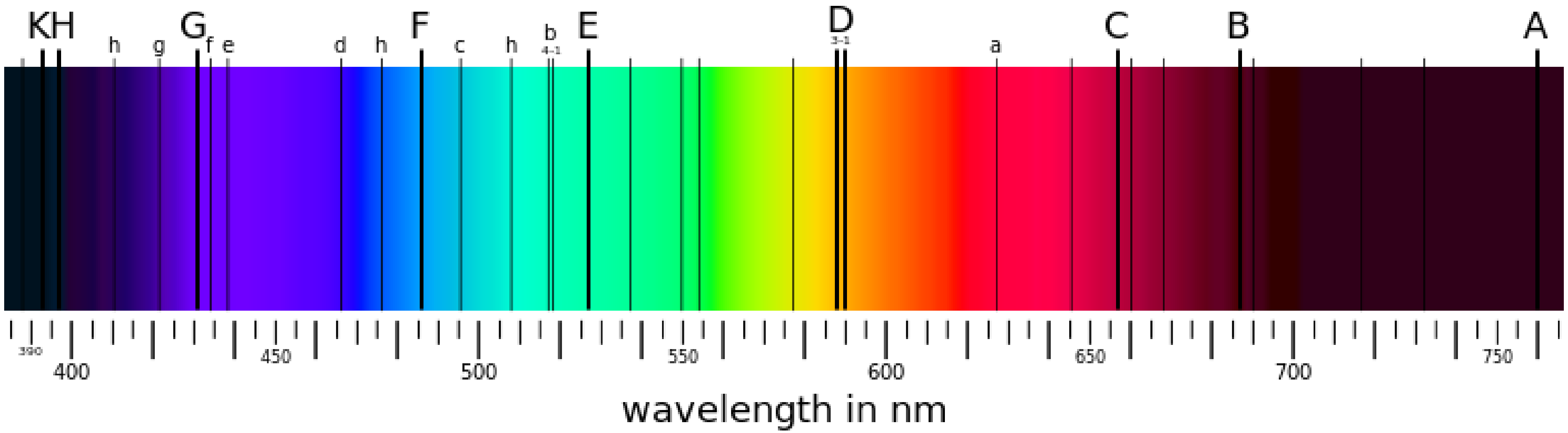
Mercury vapour releases UV photons → Hit phosphor → Phosphor glows in Visible light

Sketch & Describe the spectrum. What kind of spectrum is it?

Source 3: Sunlight



The Solar Spectrum



Designation	Element	Wavelength (nm)
y	O_2	898.765
Z	O_2	822.696
A	O_2	759.370
B	O_2	686.719
C	H_α	656.281
a	O_2	627.661
D1	Na	589.592
D2	Na	588.995
D3 or d	He	587.5618
e	Hg	546.073
E	Fe	527.039
b1	Mg	518.362
b2	Mg	517.270
b3	Fe	516.891
b4	Mg	516.733

Designation	Element	Wavelength (nm)
c	Fe	495.761
F	H_β	486.134
d	Fe	466.814
e	Fe	438.355
G'	$H\gamma$	434.047
G	Fe	430.790
G	Ca	430.774
h	$H\delta$	410.175
H	Ca^+	396.847
K	Ca^+	393.366
L	Fe	382.044
N	Fe	358.121
P	Ti^+	336.112
T	Fe	302.108
t	Ni	299.444

Sources 4a)-4i): Discharge Tubes

At the front are several discharge tube "carousels." 3 of them have tubes of:

a) Air
b) Argon (Ar)
c) Carbon Dioxide (CO_2)
d) Helium (He)
e) Hydrogen (H)
f) Neon (Ne)
g) Nitrogen (N)
h) Water Vapour (H_2O)

The fourth carousel has an "unknown" gas

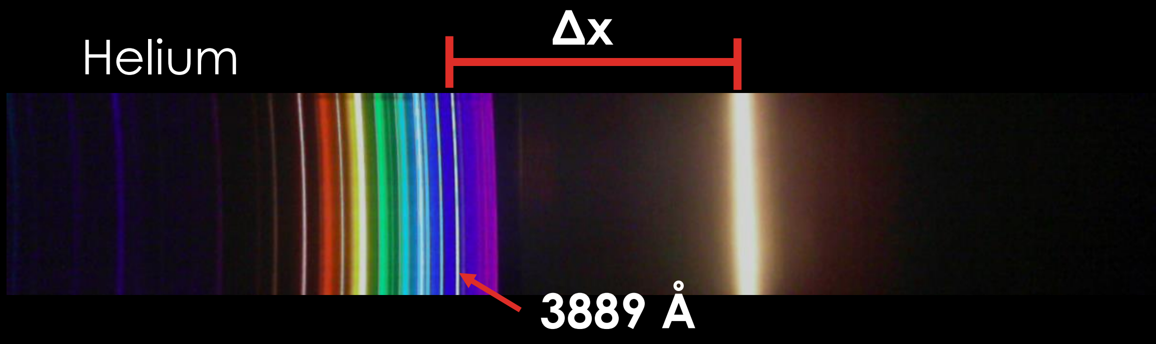
Sketch & Describe each source. What kind of spectrum is it?

Identify the Mystery Element!

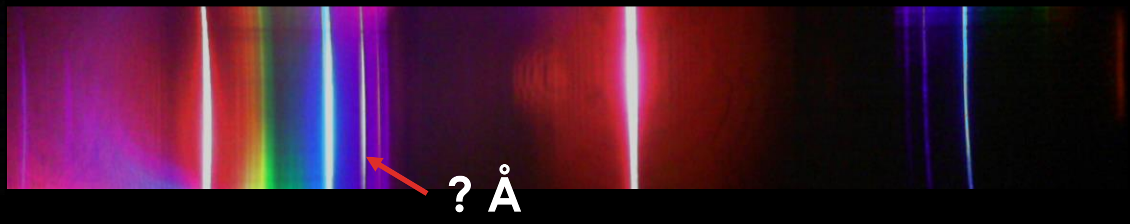
PART II: SPECTROGRAPH CALIBRATION USING HELIUM TO ID HYDROGEN

- In this part of the lab, you will be using the known wavelengths of Helium to determine the wavelengths of the first three Hydrogen Balmer lines
- This will be done using **calibrated images** of the two elements
  - The position of a line in a diffraction grating spectrum is dependent on **1)** The **wavelength** of the light, **2)** The properties of the grating, and **3)** the distance to the source
  - **As long as nothing is changed between the two images** besides the element, we can use the helium image to convert between **line displacement in pixels** and **wavelength in angstroms**

Helium

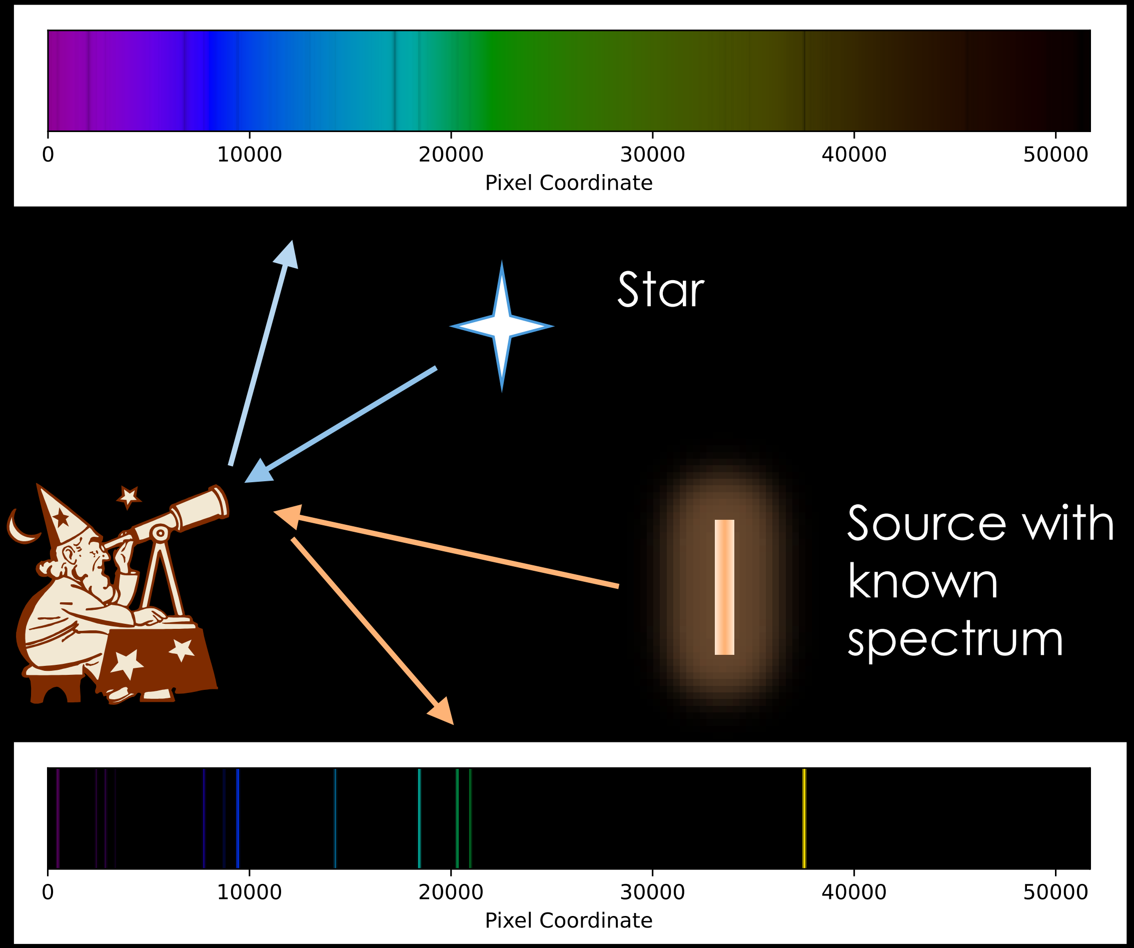


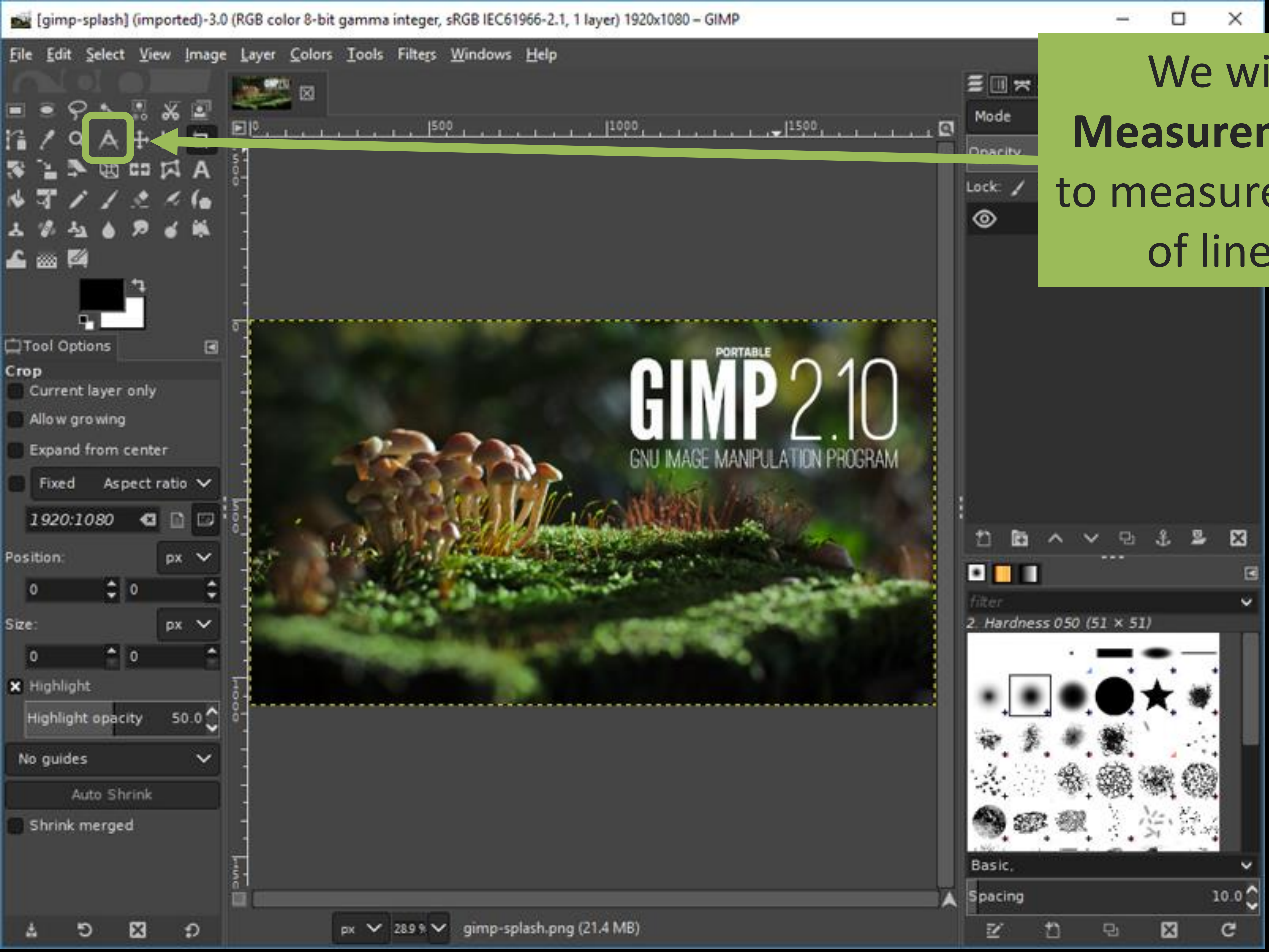
Hydrogen



PART II: SPECTROGRAPH CALIBRATION HOW ASTRONOMERS ID WAVELENGTHS

- Images of spectra are recorded in a digital image → grid of “pixels” of set size
- Measurable quantity: separation
- Line separation from 0th order is proportional to wavelength of light
- Same equipment = same proportional separation for all spectra
- If we take a picture of a known spectrum, eg. Discharge tube, we can use it to map pixels → wavelength
- The lines won’t be the same, but the *relationship* between separation and wavelength will → *Calibration*

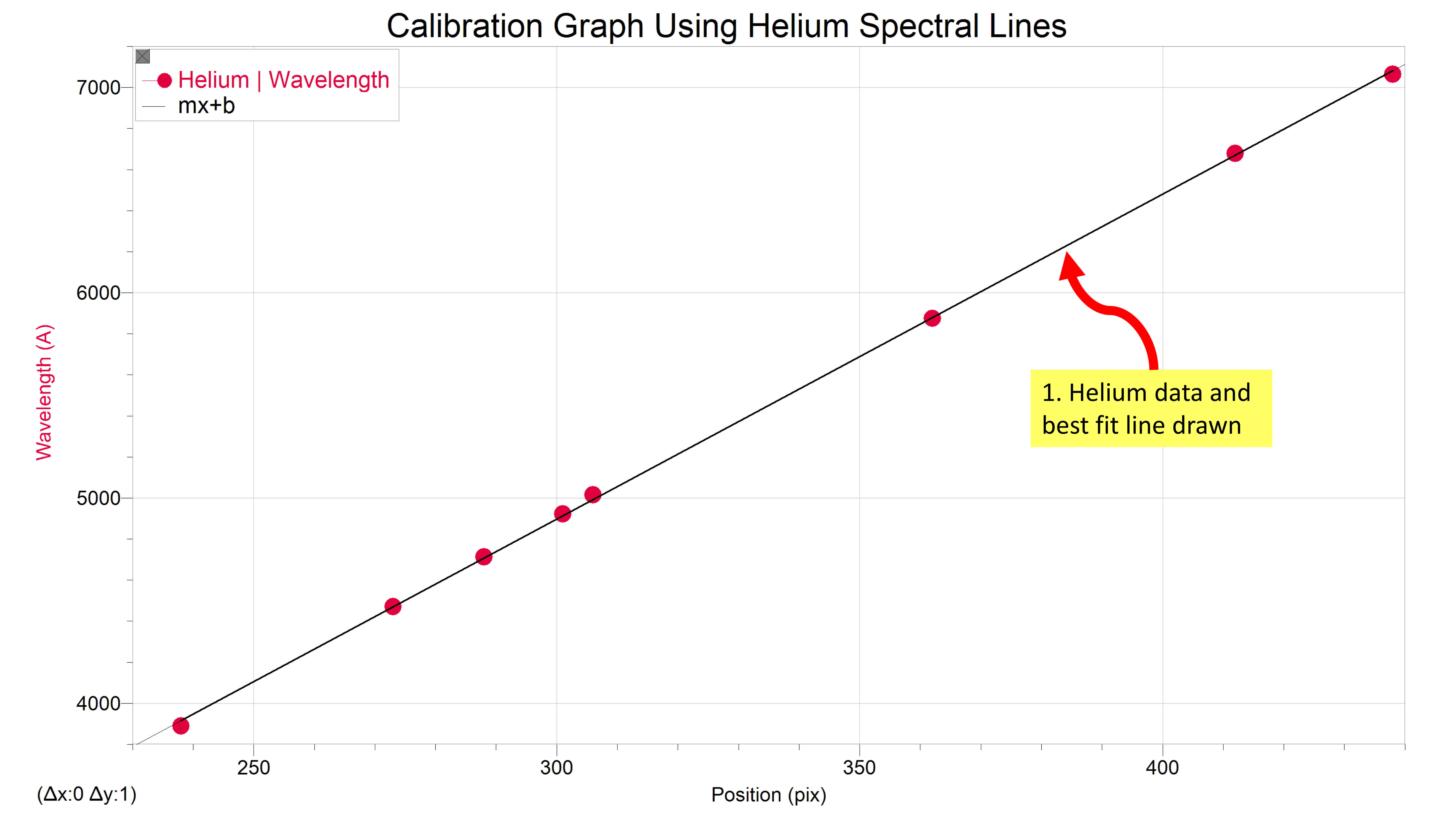




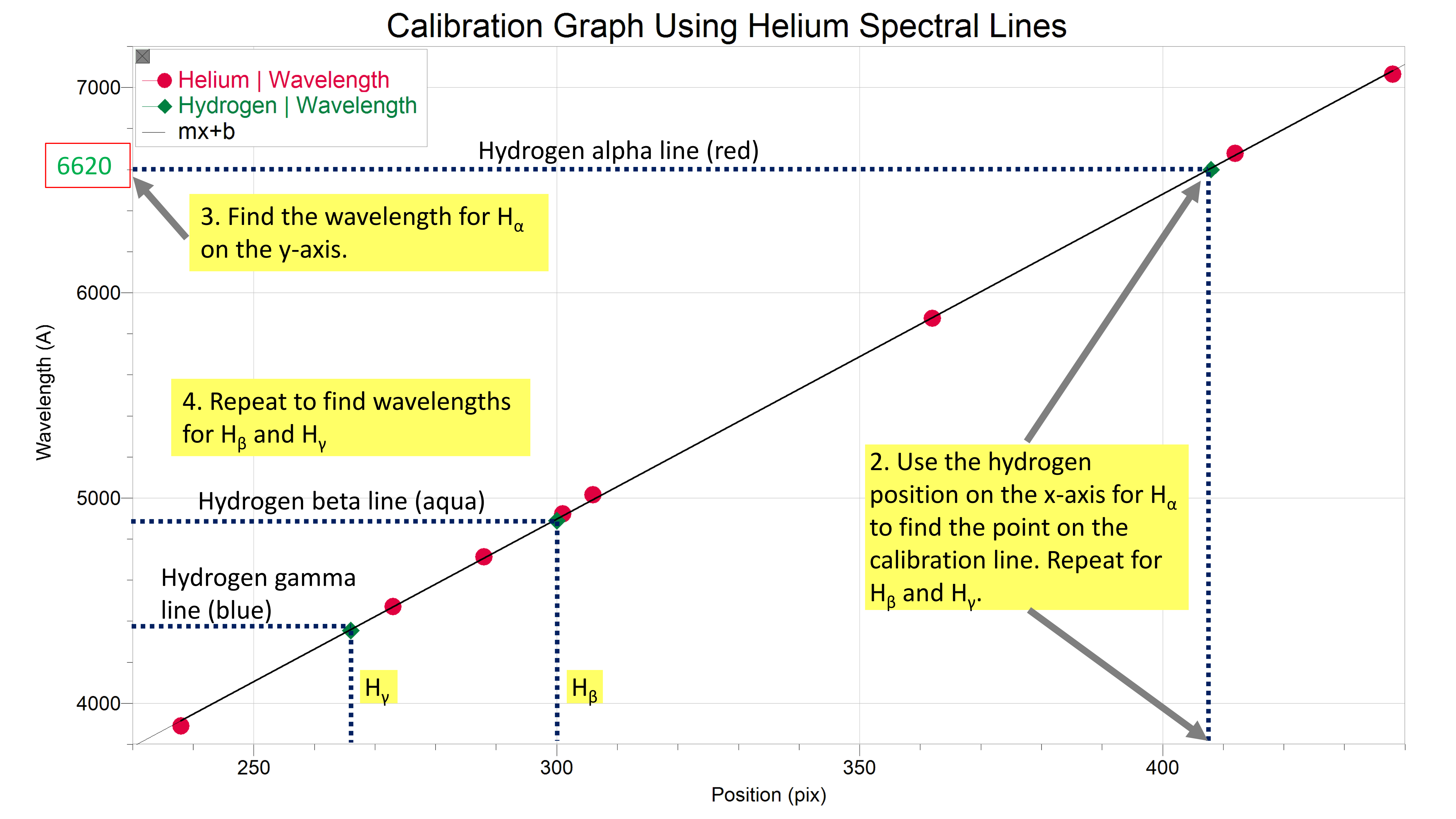
We will be using the **Measurement tool** in GIMP to measure the displacement of lines in the image

It looks like a compass

If you can't find it, hold Shift and type "m"
Or
Tools > Measure



Calibration Graph Using Helium Spectral Lines
Helium | Wavelength
mx+b
7000
6000
5000
4000
Wavelength (A)
250
300
350
400
Position (pix)
(Δx:0 Δy:1)
1. Helium data and best fit line drawn



Calibration Graph Using Helium Spectral Lines
Helium | Wavelength
Hydrogen | Wavelength
mx+b
6620
Hydrogen alpha line (red)
3. Find the wavelength for H_α on the y-axis.
4. Repeat to find wavelengths for H_β and H_γ
Hydrogen beta line (aqua)
Hydrogen gamma line (blue)
2. Use the hydrogen position on the x-axis for H_α to find the point on the calibration line. Repeat for H_β and H_γ.
H_γ
H_β
7000
6000
5000
4000
Wavelength (A)
250
300
350
400
Position (pix)