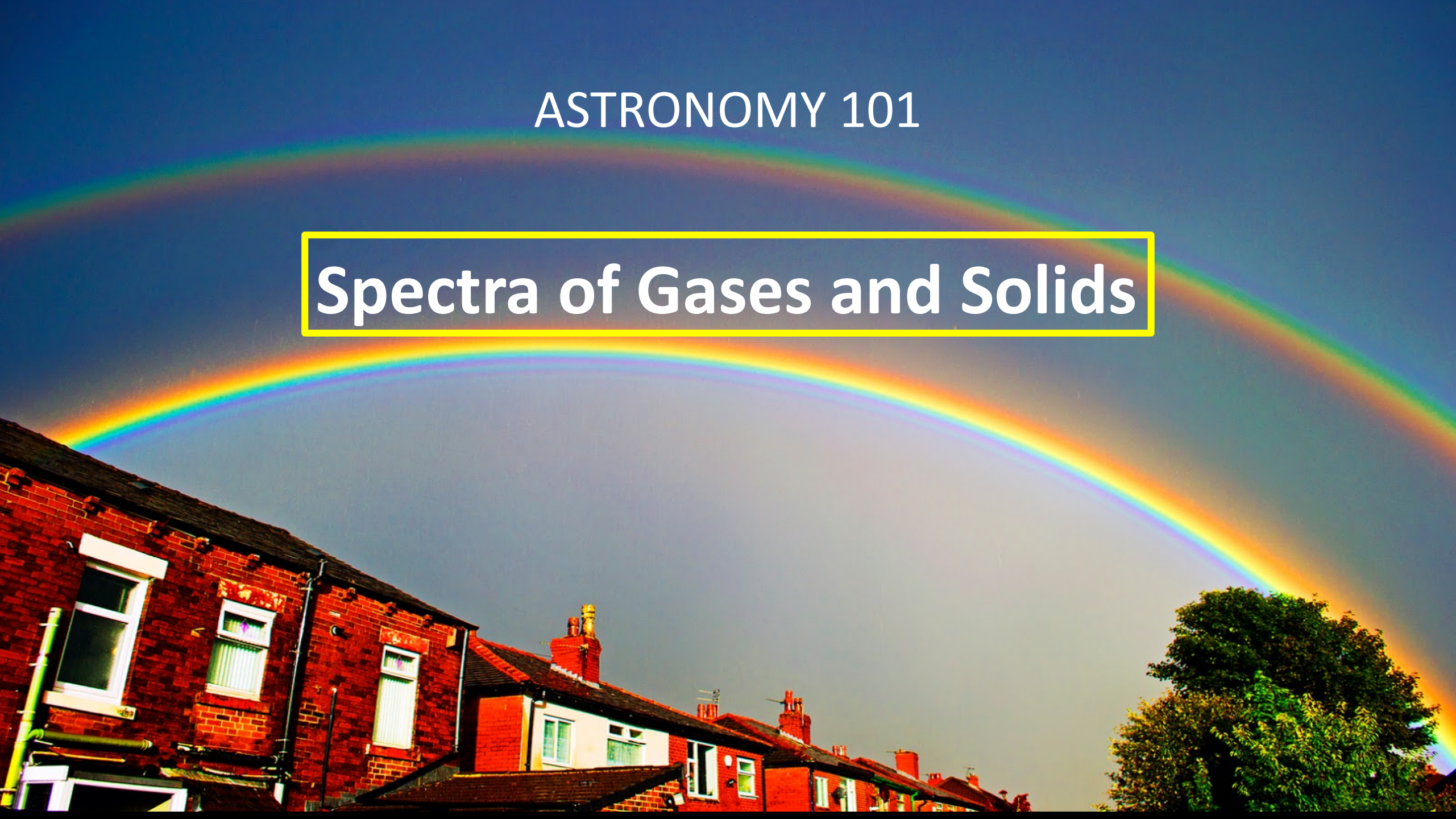
ASTRONOMY 101

Spectra of Gases and Solids

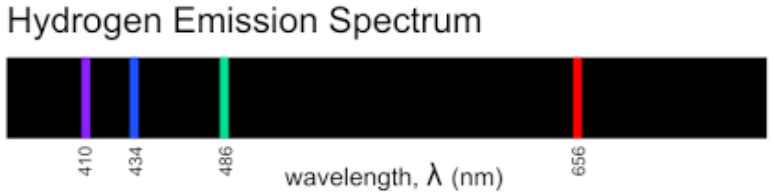


Circular Rainbows

Spectra Lab
Learning Objectives

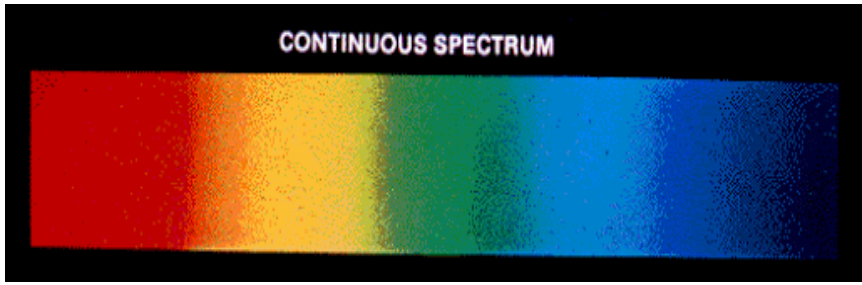
1. Nature of light → electromagnetic radiation
2. Generation of a spectrum
3. Types of spectra (continuum, absorption and emission)
4. Measurement of wavelengths of atomic spectral lines
5. Identification of an unknown element by its spectrum

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



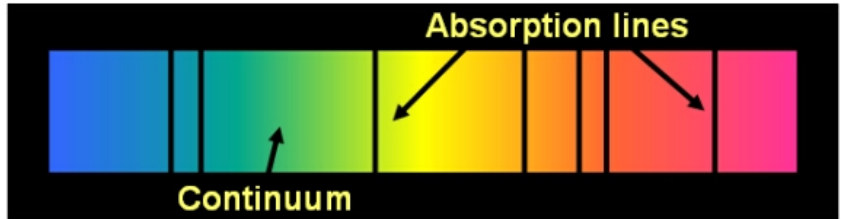
From spectral lines astronomers can determine:

- 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

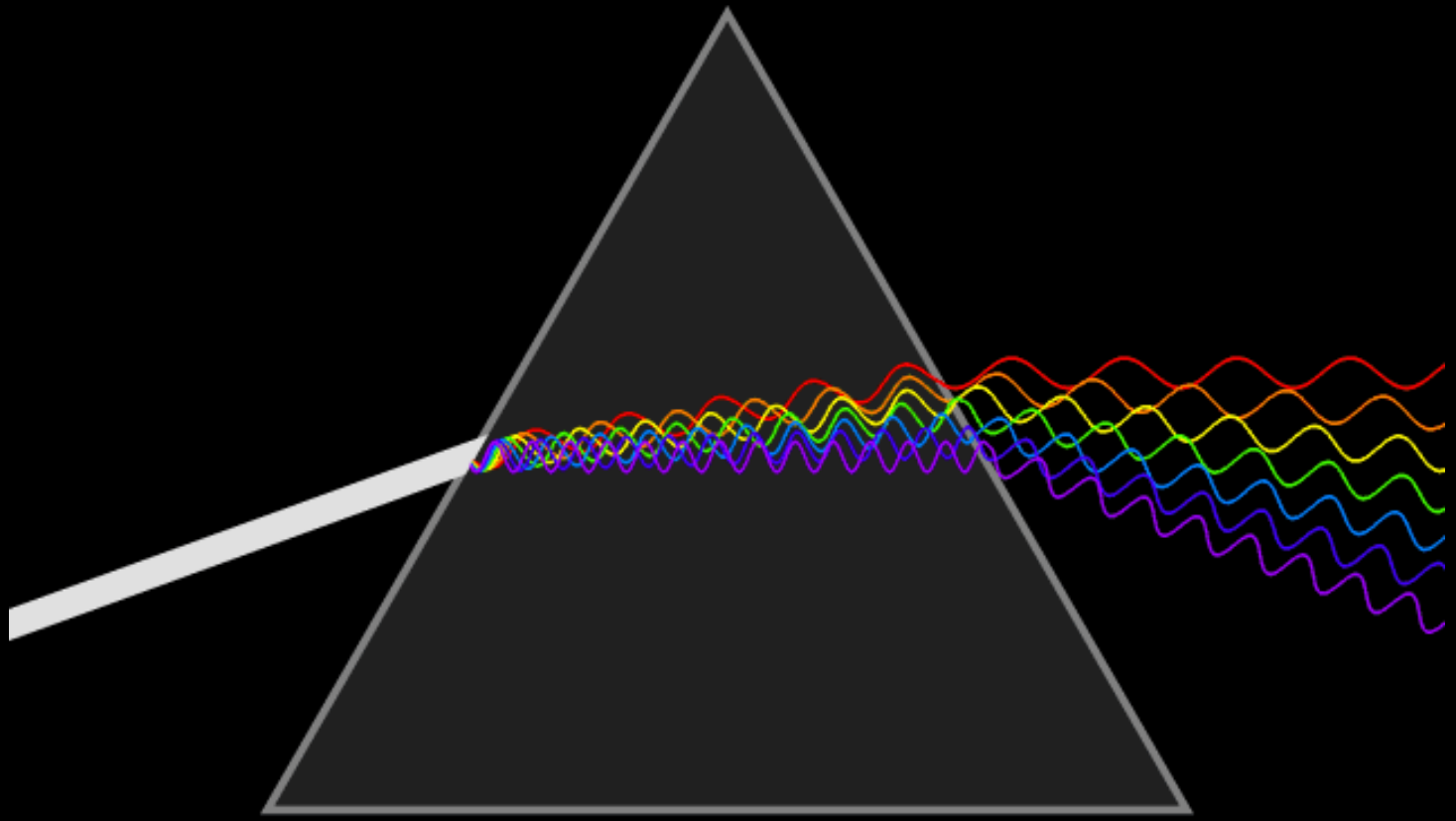


- internal temperature from spectral line width
- the magnetic field from line splitting and polarization
- stellar winds from x-ray emissions
- orbital period and velocity from line movement over time (Doppler Shift)
- the physical changes in the star from line intensity changes over time
- the material around stars - the interstellar medium (ISM).

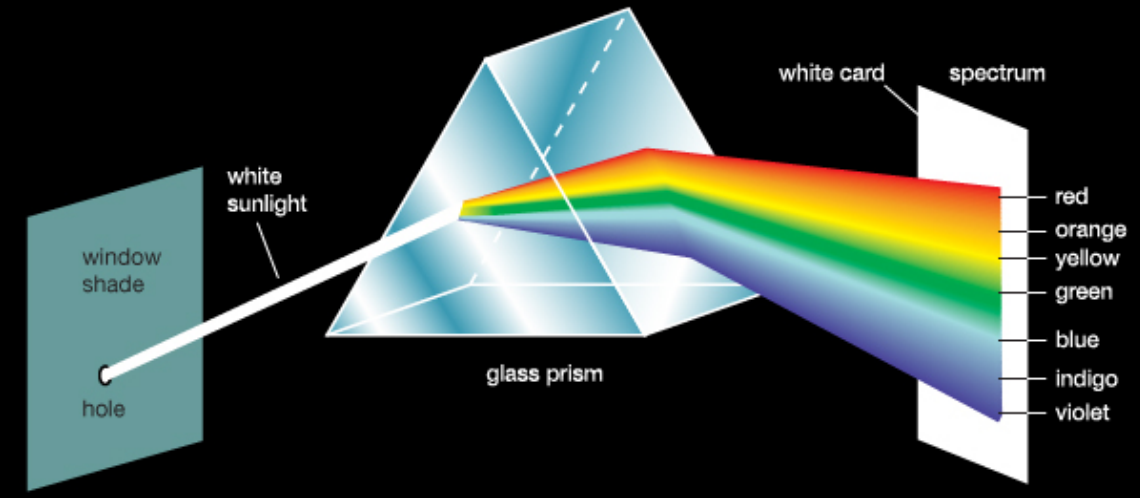
Spectroscopy is a fundamental tool used to study the universe.



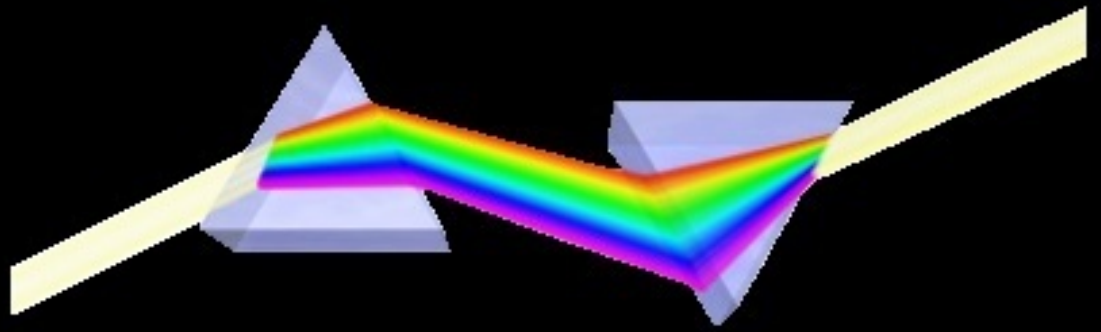
Light Refraction Through a Prism



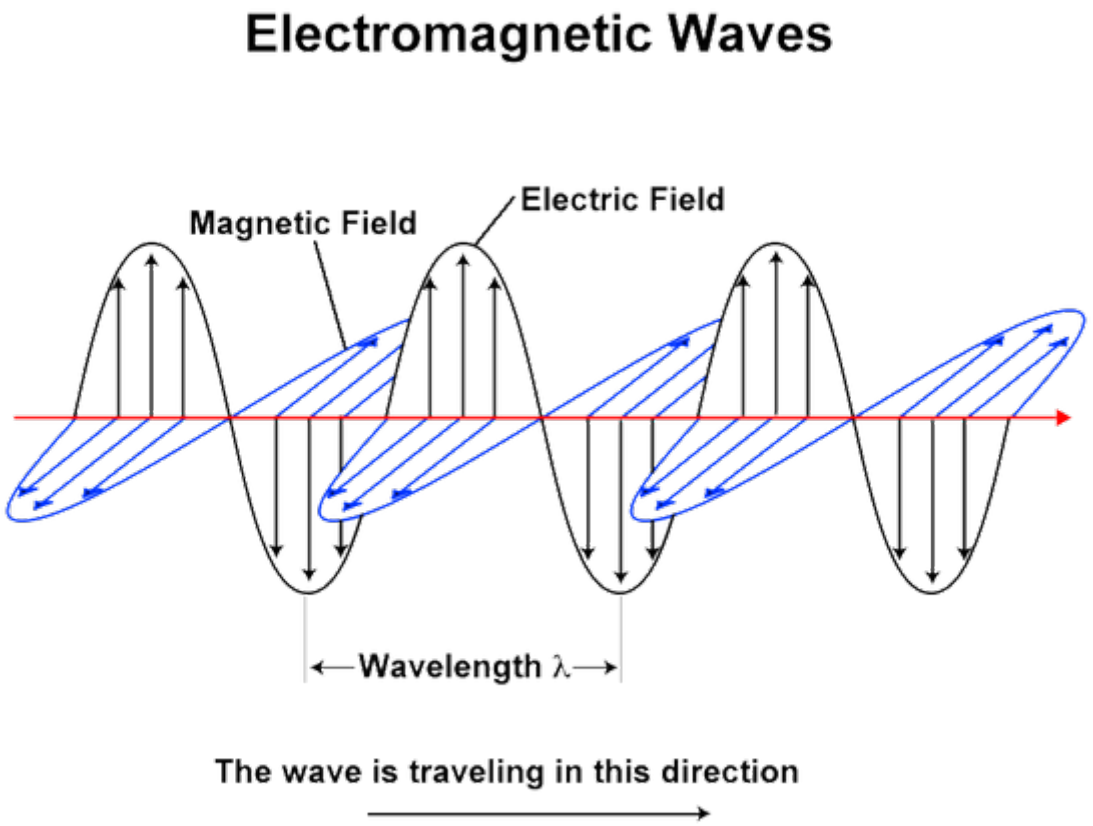
Prisms



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.

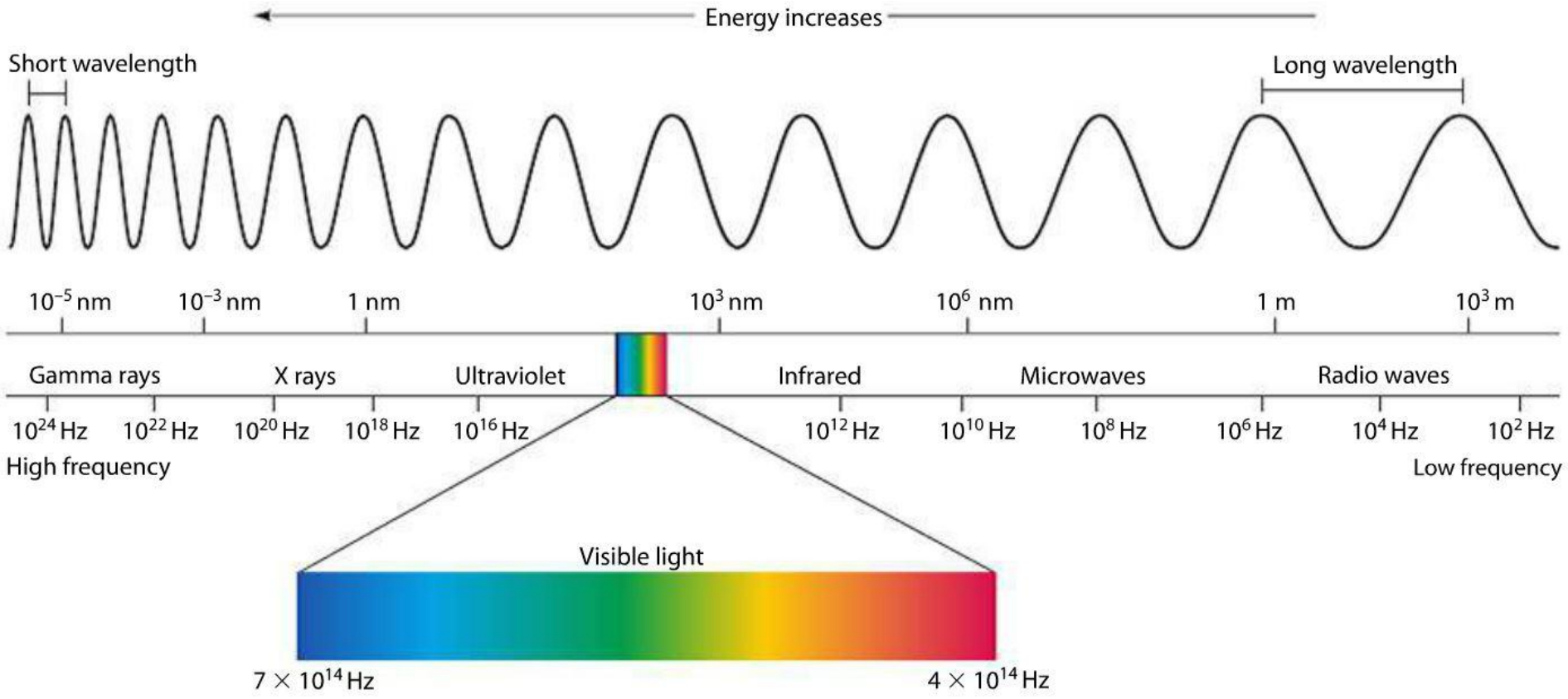


A Few Light Facts

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

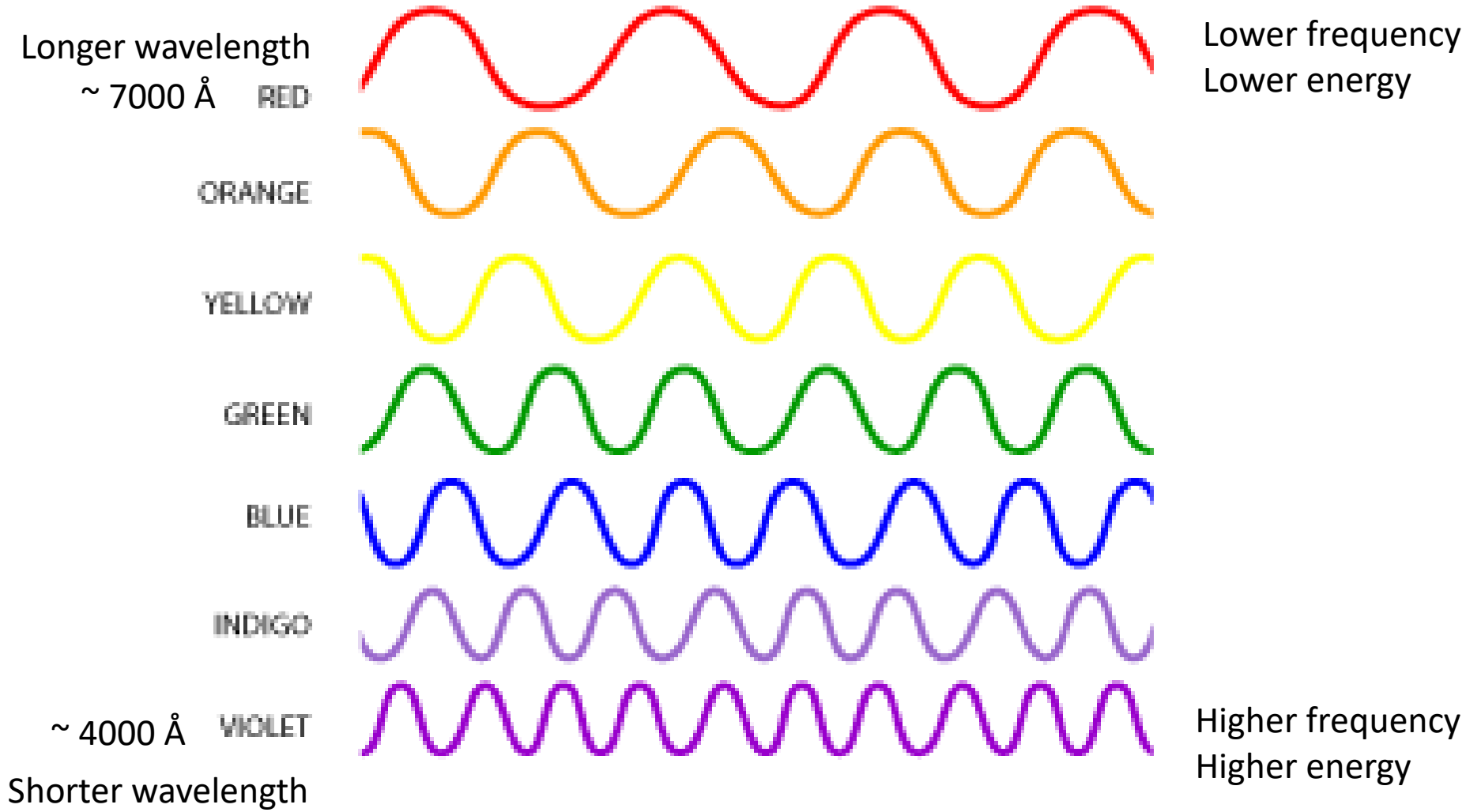


4000 Å = 400 nm

7000 Å = 700 nm

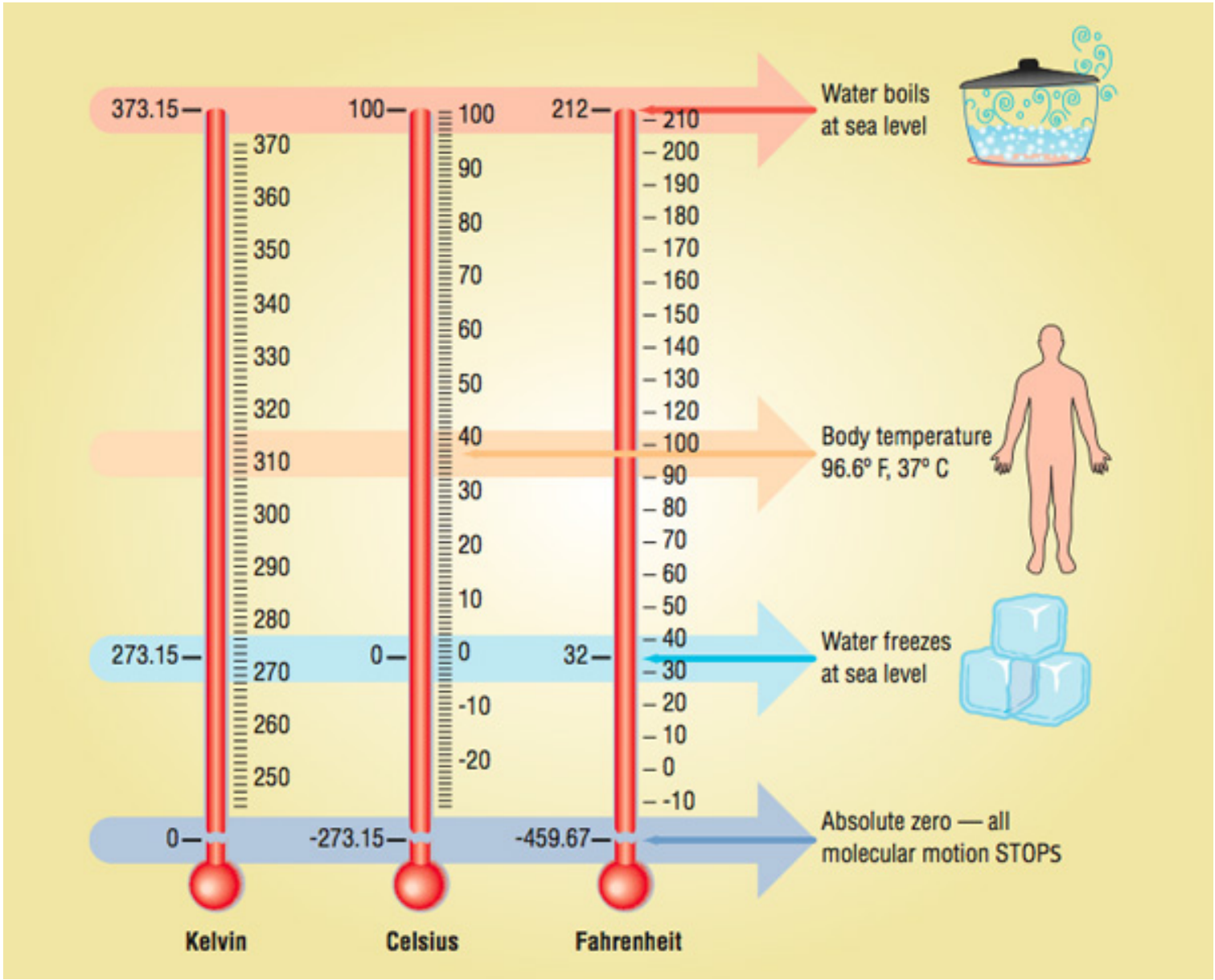
velocity = frequency x wavelength = 299 792.458 km/s (speed of light in a vacuum)
$\sim 300\,000\ \mathrm{km/s}$

The Visible Spectrum

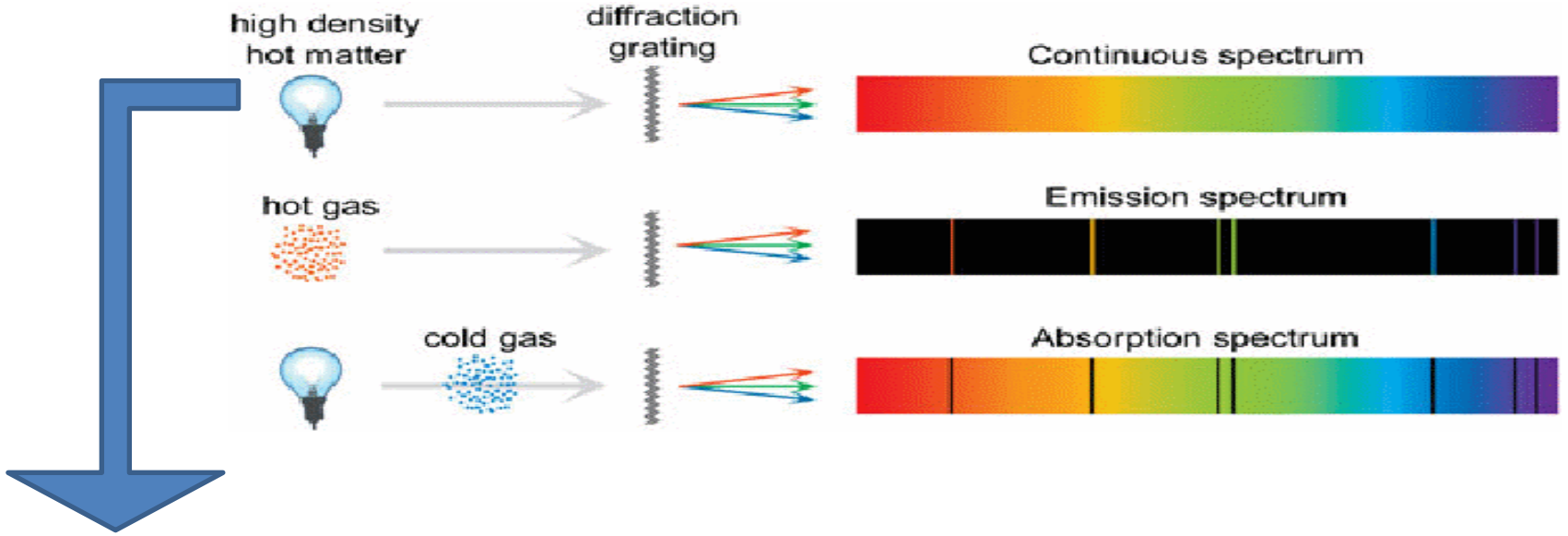


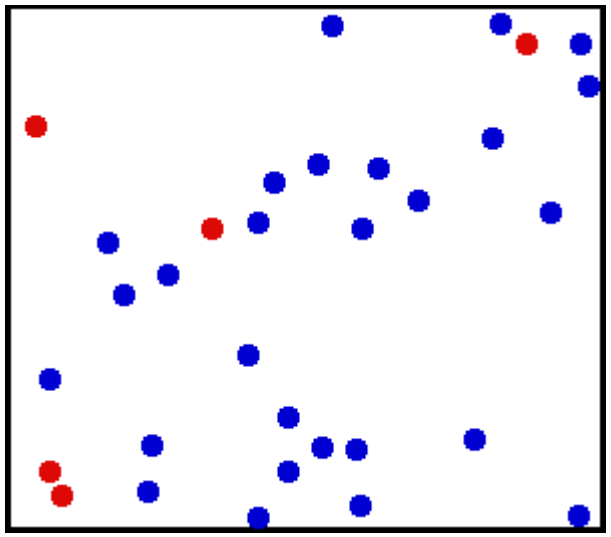
The **Ångström** (Å) is a unit of length equal to 10^{-10} m (one ten-billionth of a metre) named after the Swedish physicist Anders Jonas Ångström (1814–1874).

Temperature Scales



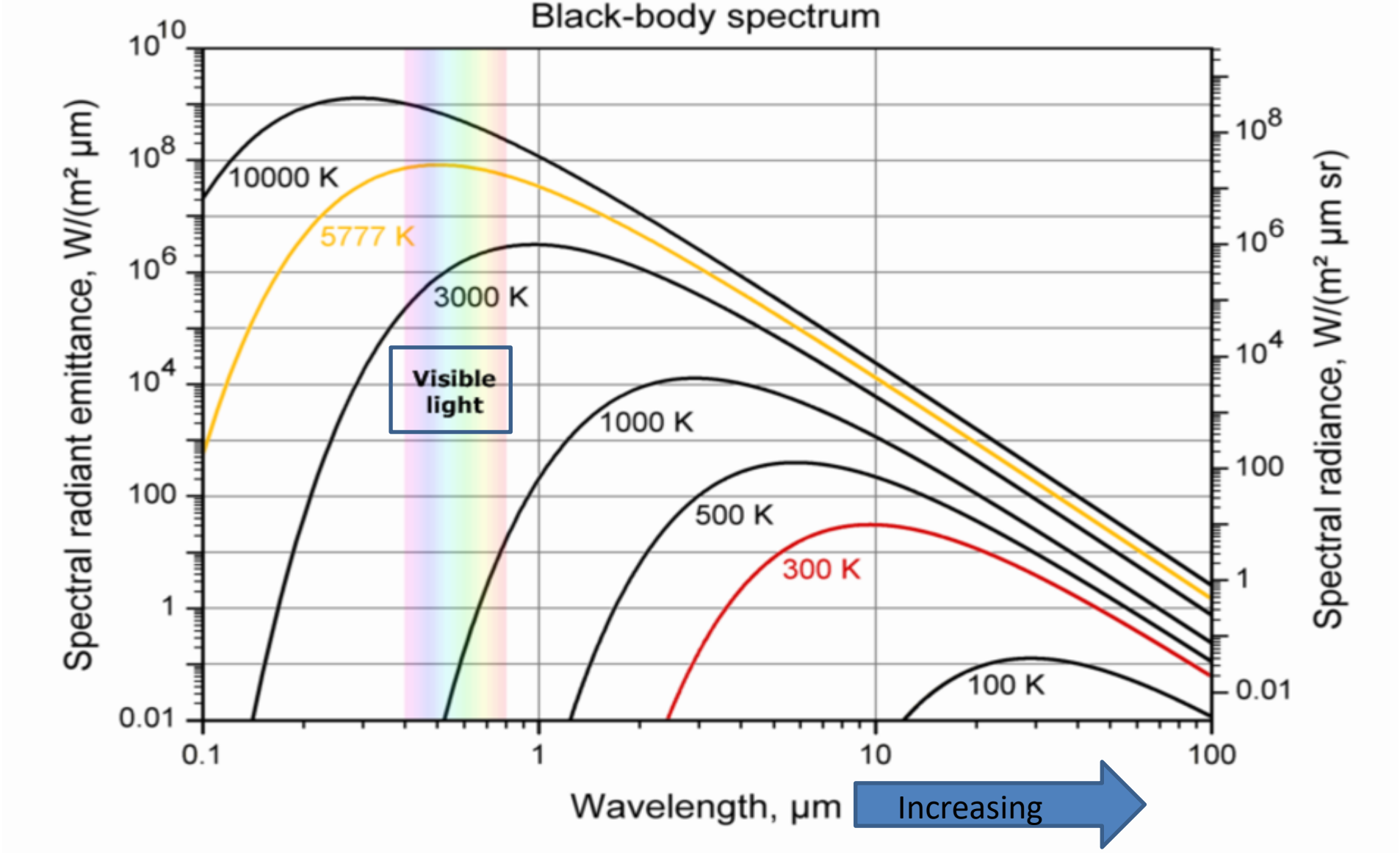
Emission and Absorption Spectra

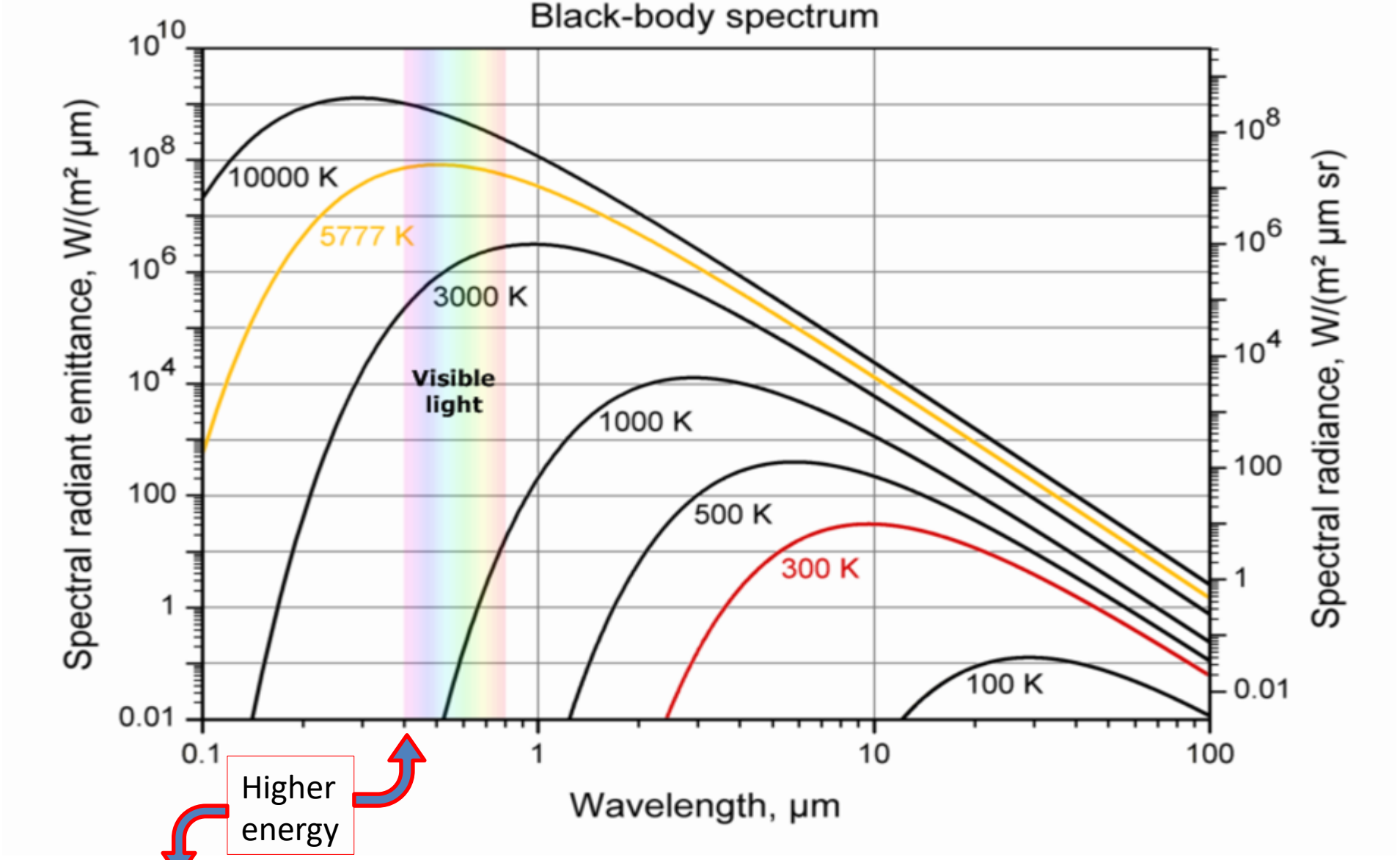


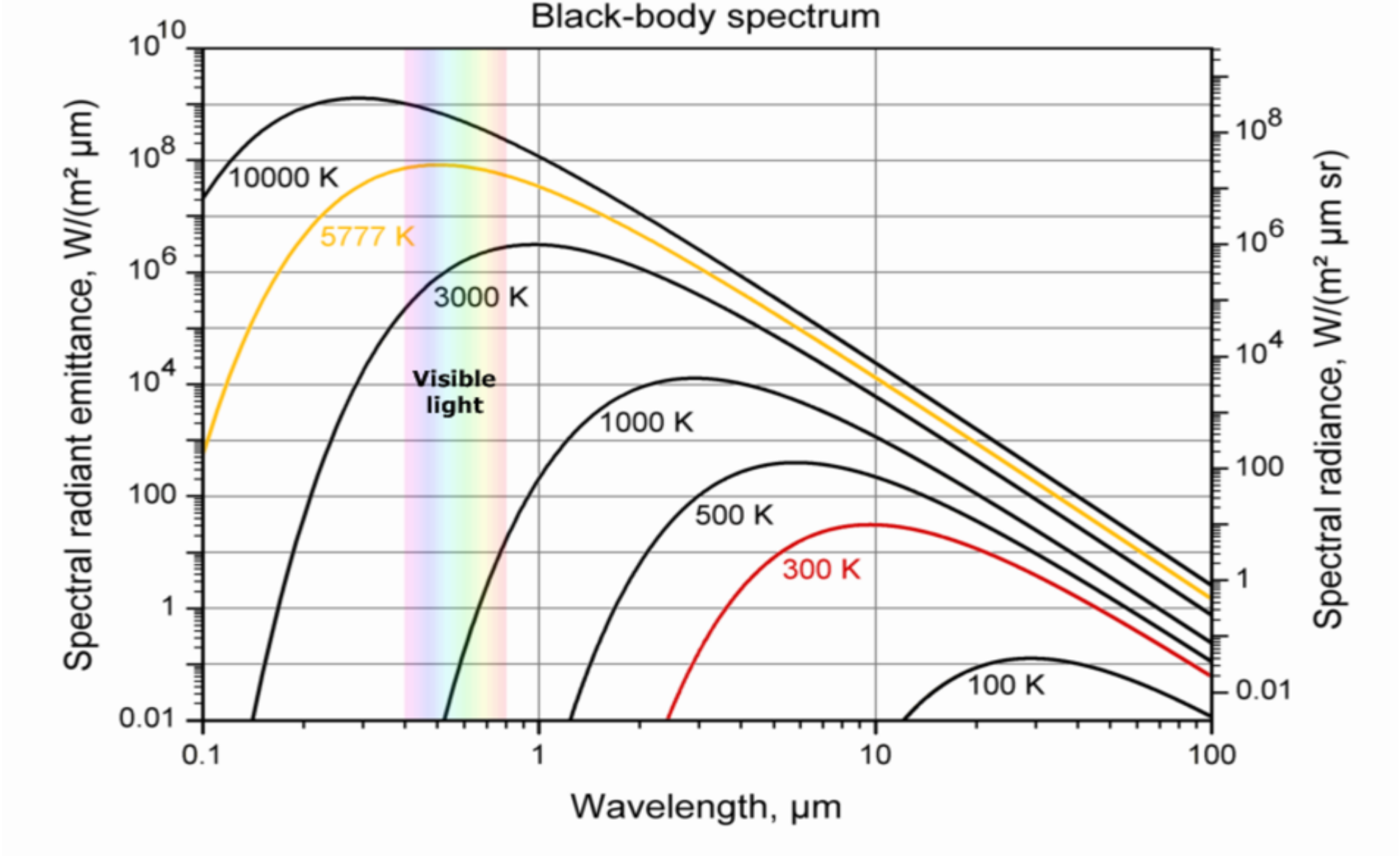


Continuous spectrum is produced by hot, dense objects

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

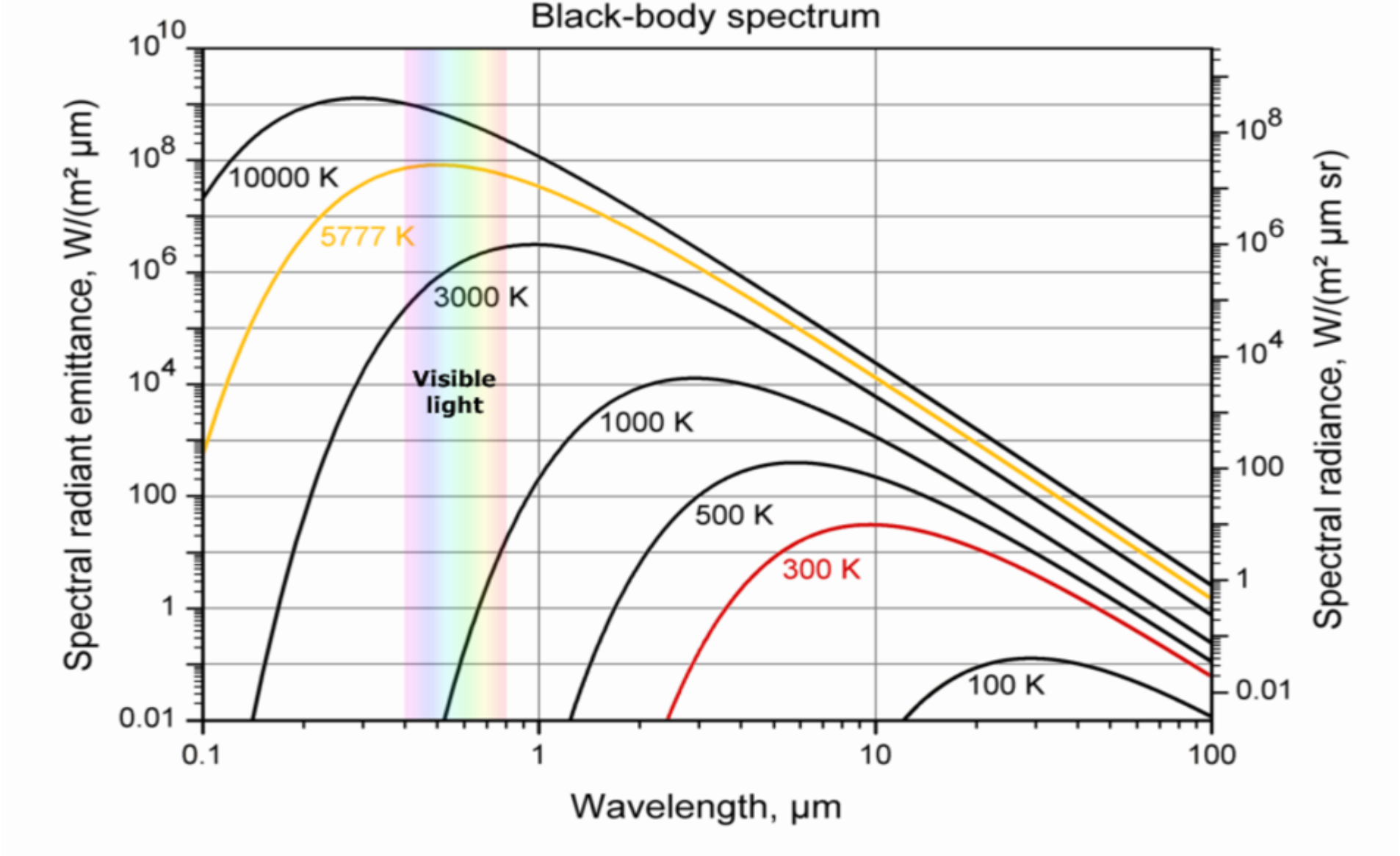

Black-body spectrum
Spectral radiant emittance, W/(m² μm)
Spectral radiance, W/(m² μm sr)
10000 K
5777 K
3000 K
1000 K
500 K
300 K
100 K
Visible light
0.1
1
10
100
Wavelength, μm
Increasing
Increasing
Energy


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



Stefan–Boltzmann Law:

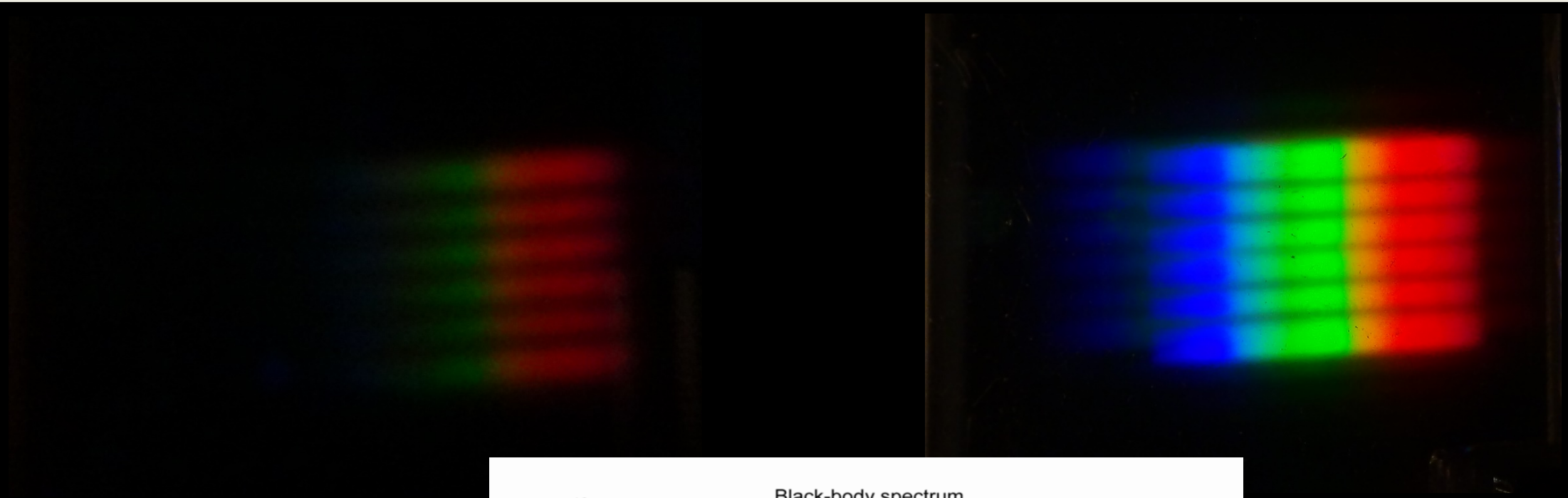
Total energy radiated per unit surface area $\propto$ (Temperature)^4



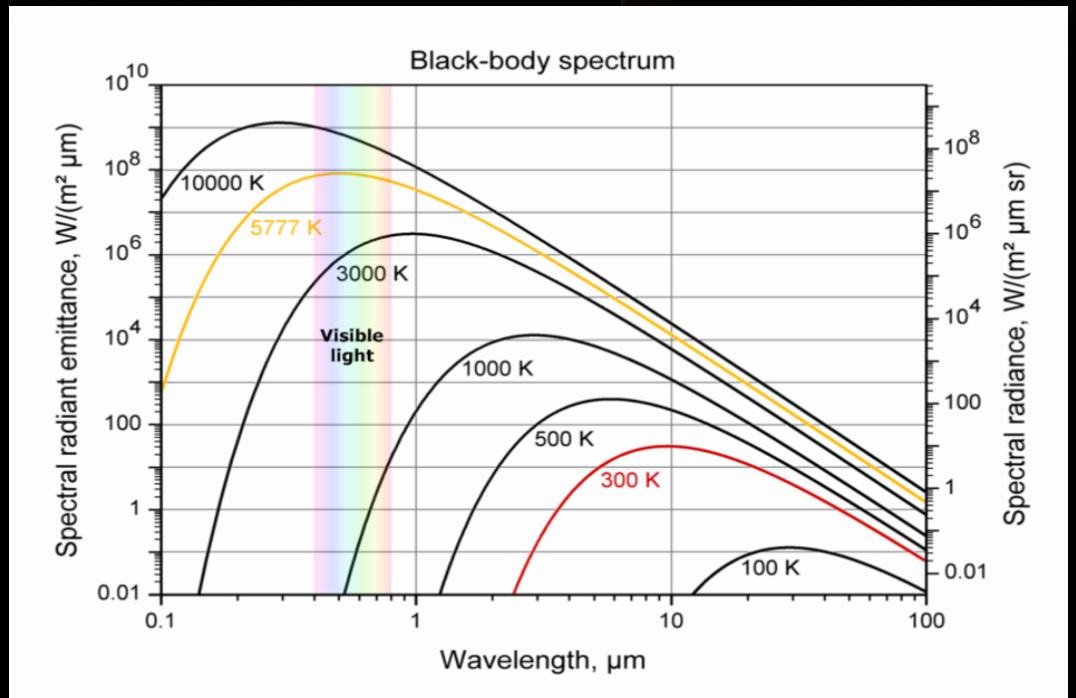
Wien's Law:

A higher temperature means a higher peak frequency (lower wavelength)

Incandescent Spectrum

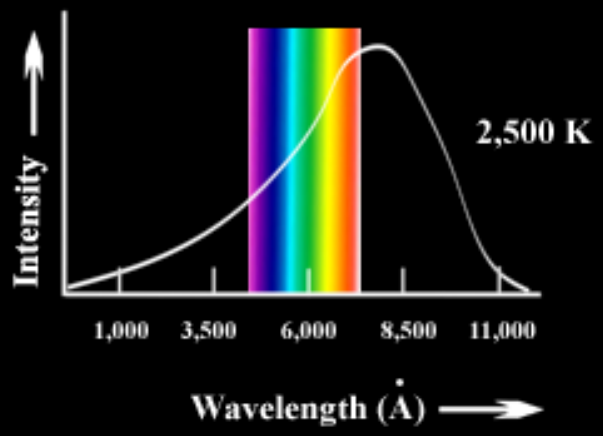


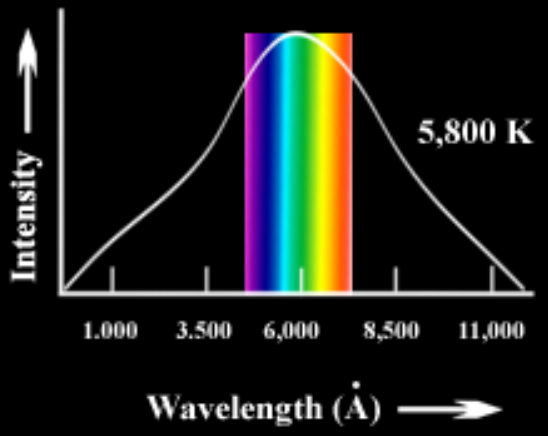
Cool tungsten filament
T ≈ 1000 K

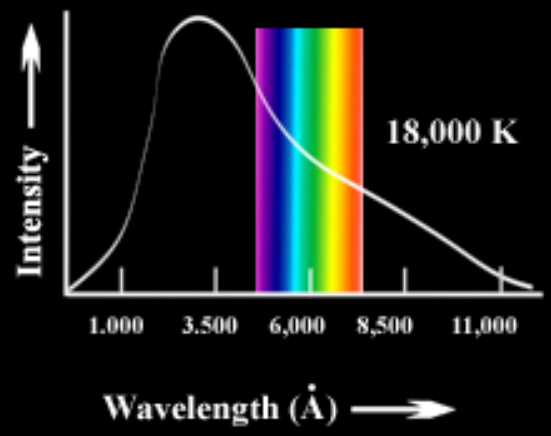


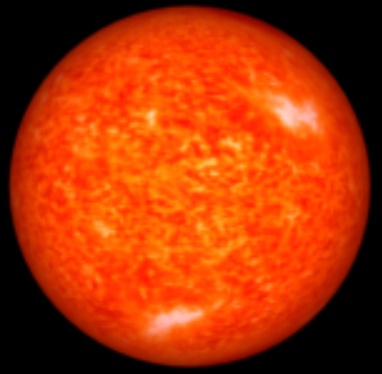
Hot tungsten filament
T ≈ 2800 K (melts at 3695 K)

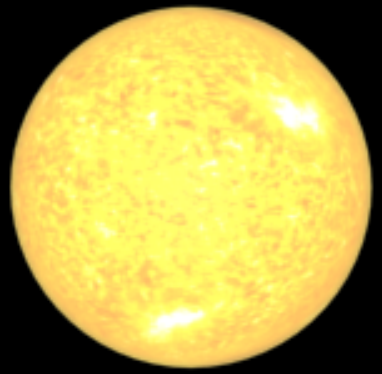
Star Temperature and Colour

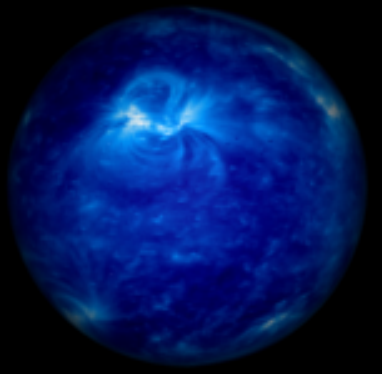






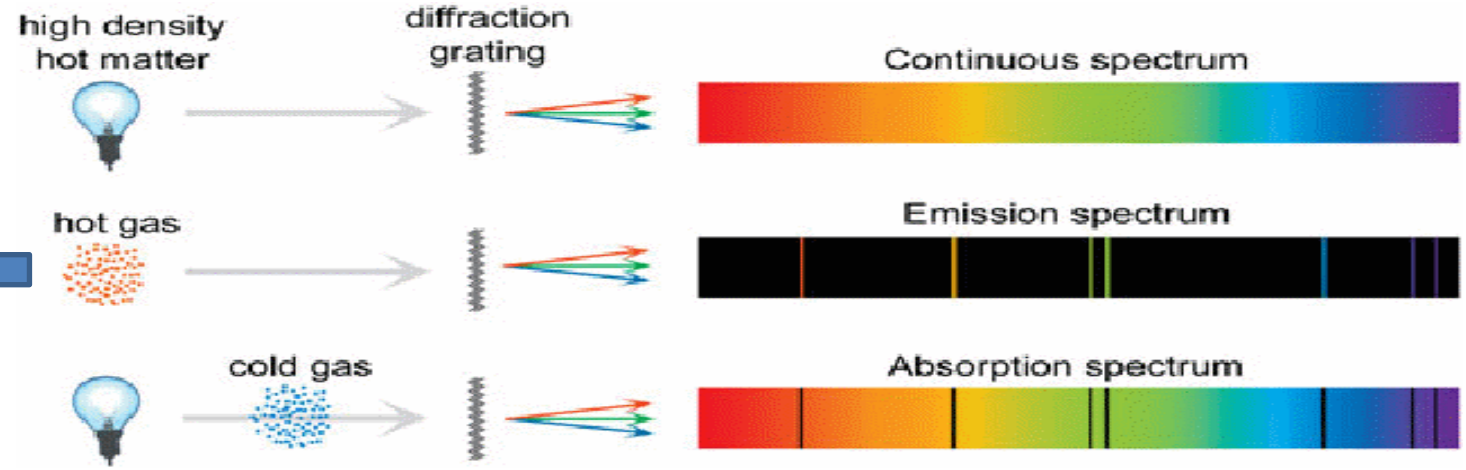




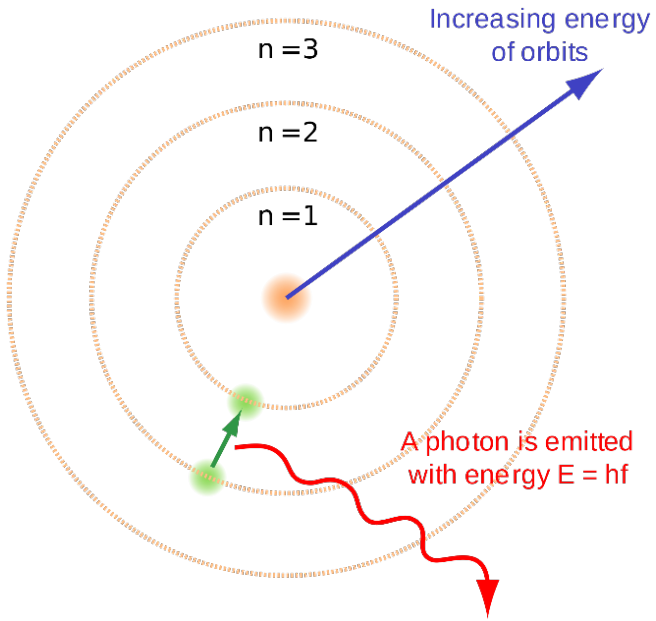


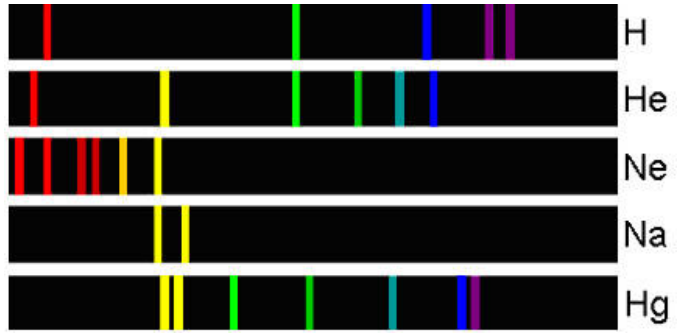
Colors are exagerrated

Emission and Absorption Spectra

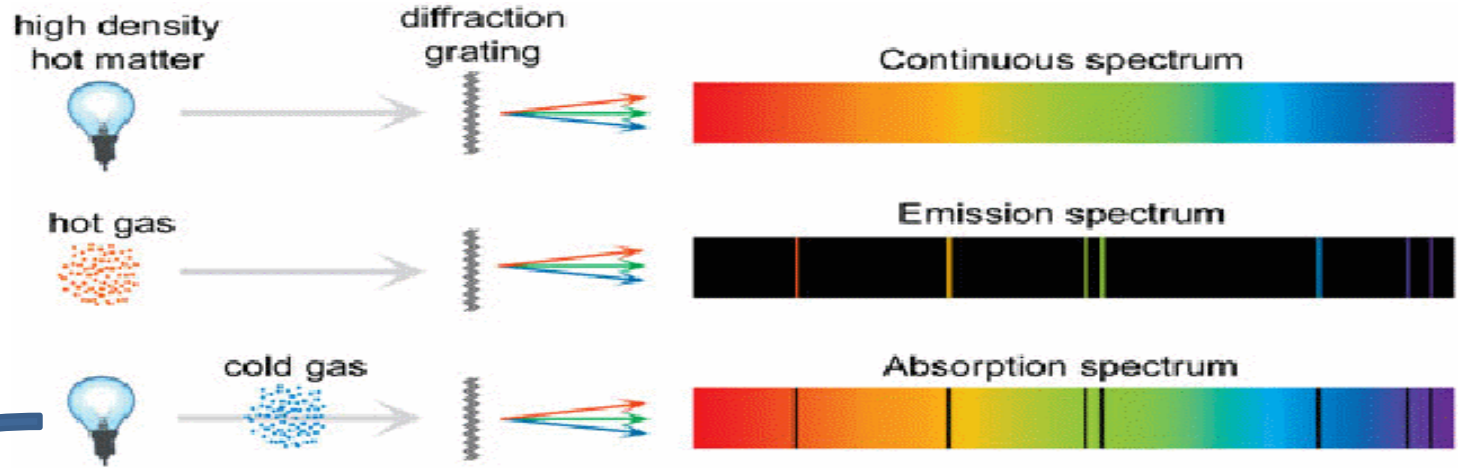


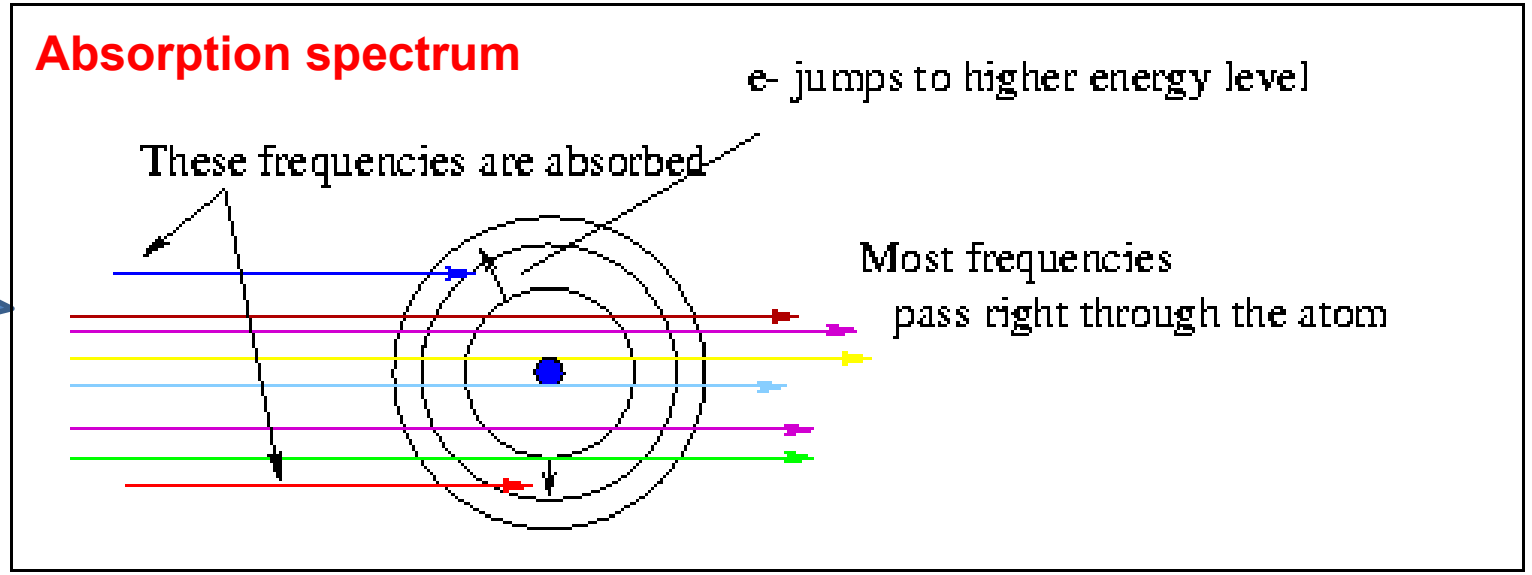
Emission spectrum occurs when the electrons of an excited atom, element or molecule move to lower energy levels.



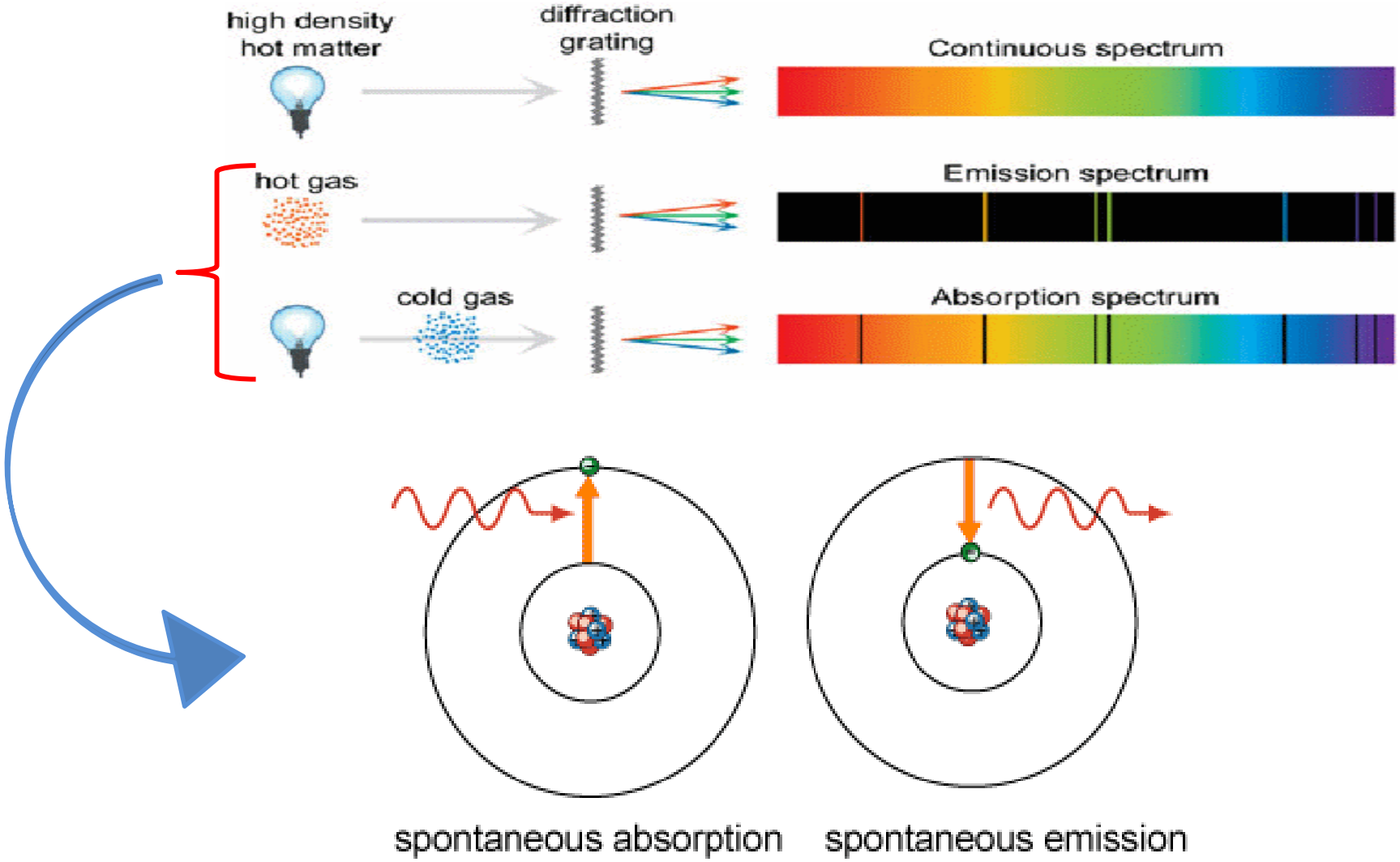


Emission and Absorption Spectra

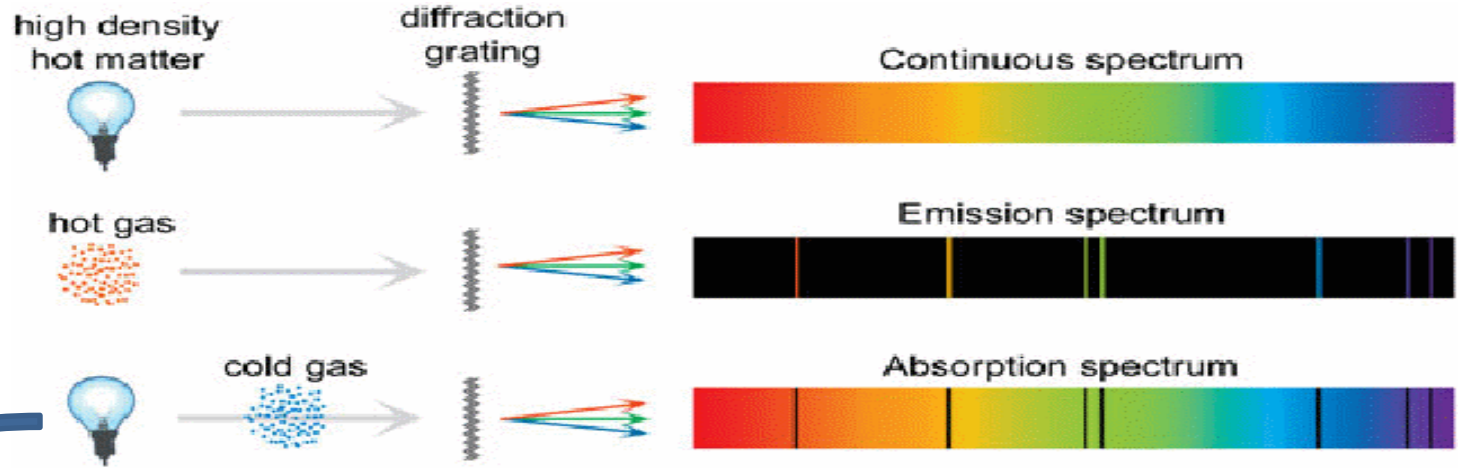


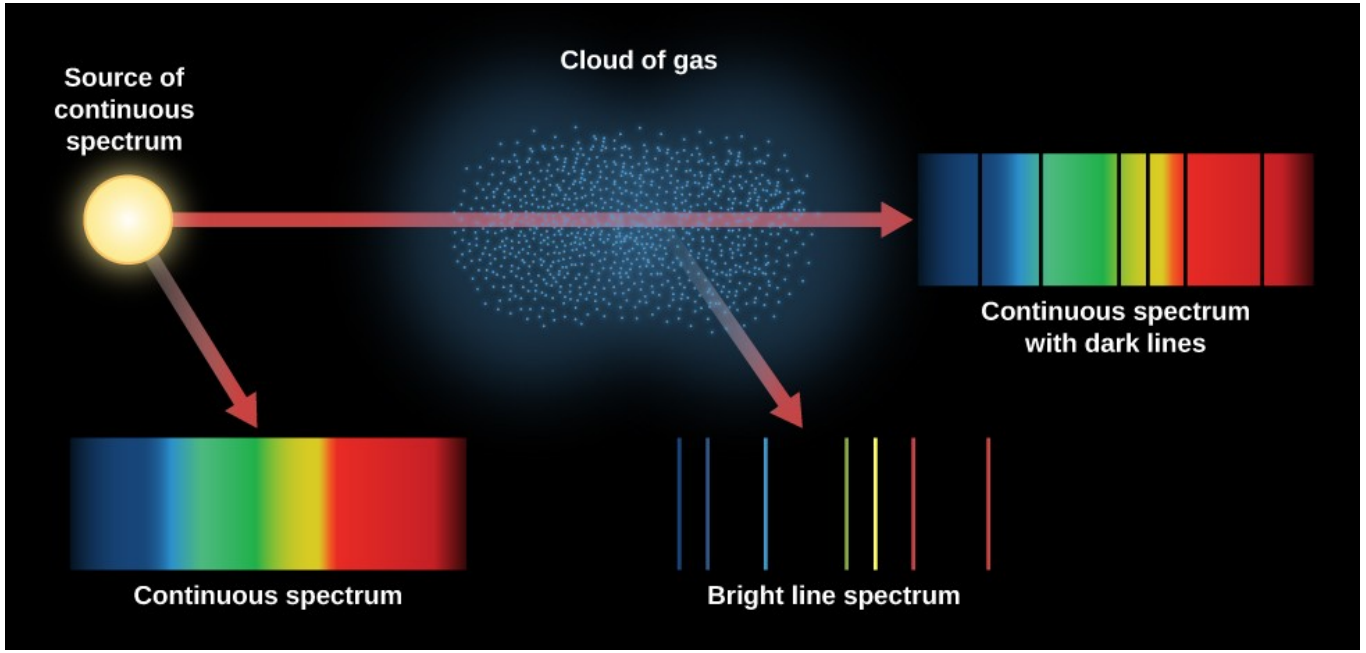


Emission and Absorption Spectra



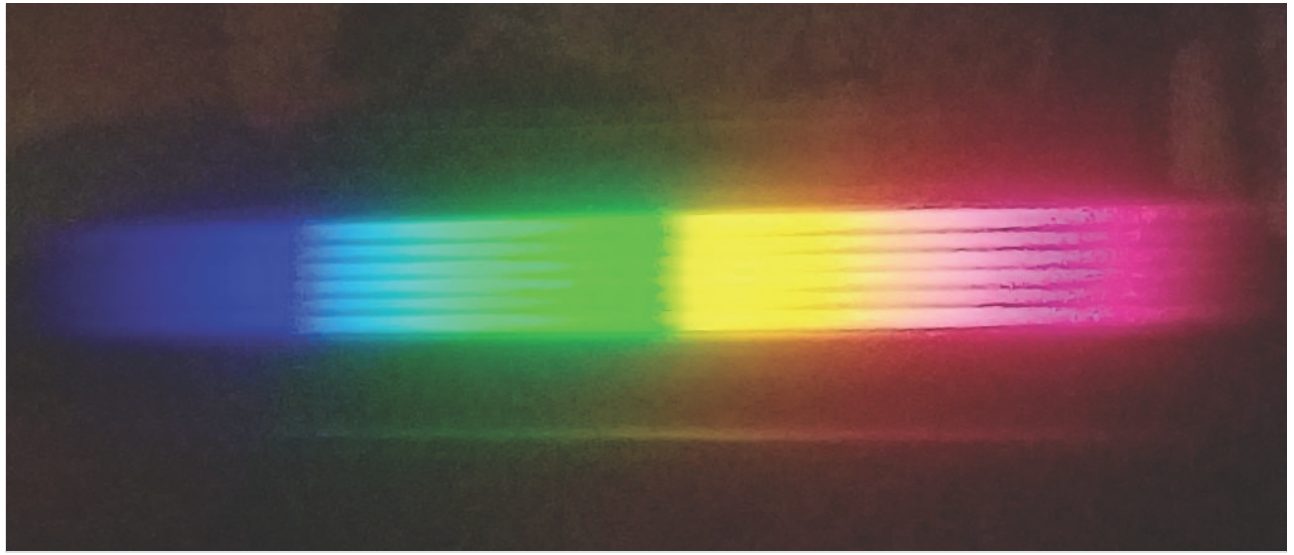
Emission and Absorption Spectra

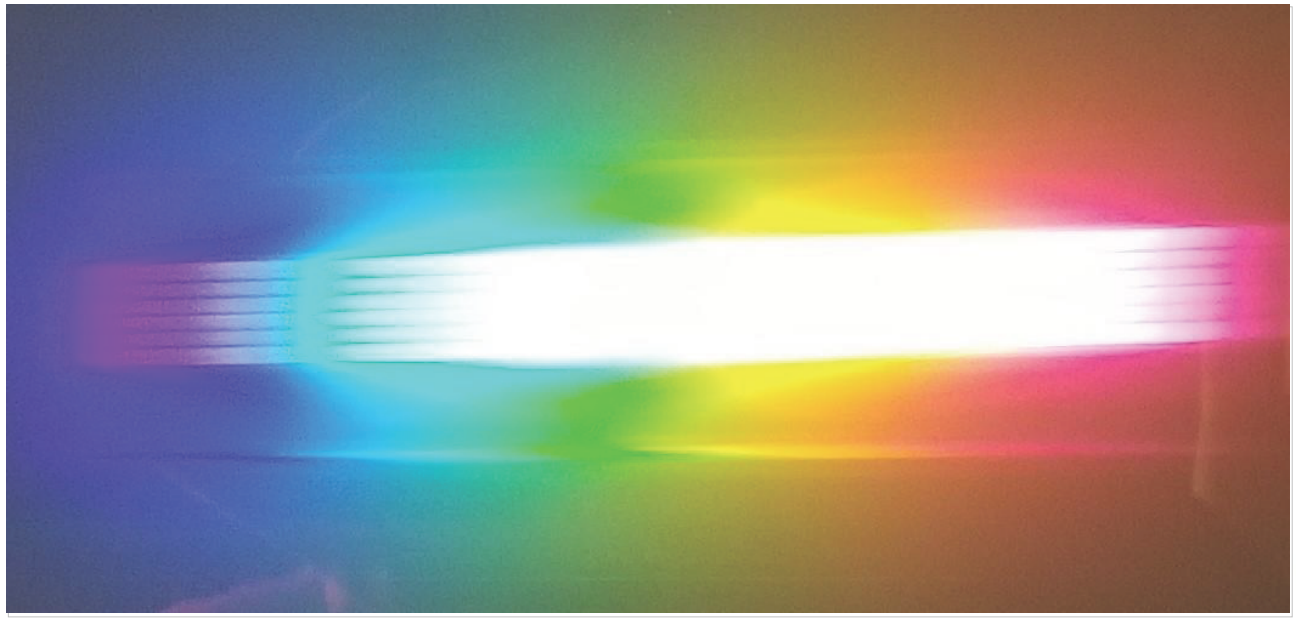




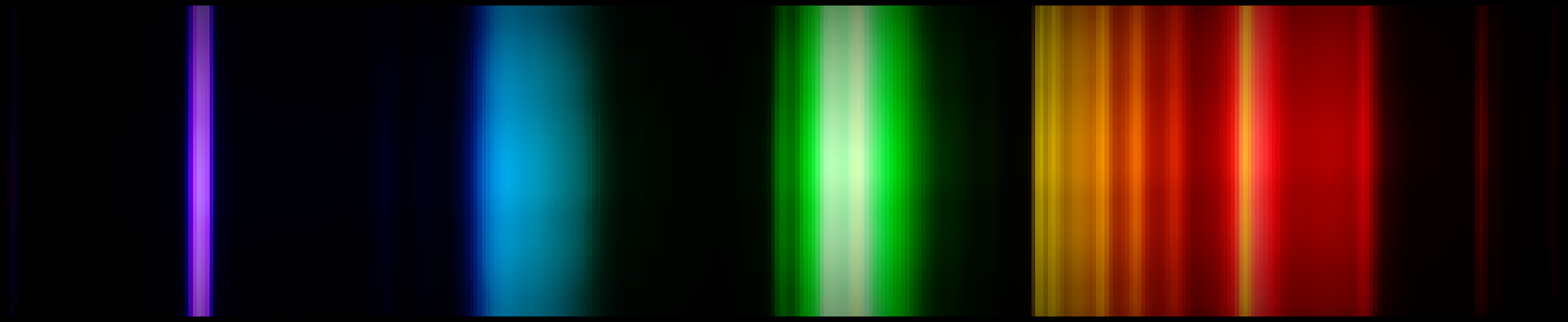
Part I: Visual observation of different types of spectra.

Question 1: Incandescent Bulb Spectrum

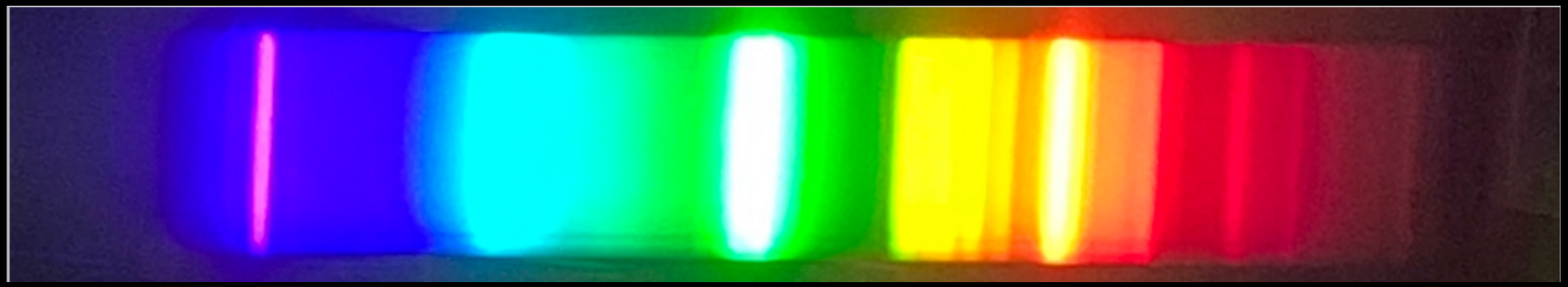




Question 2: Fluorescent Tube Spectrum

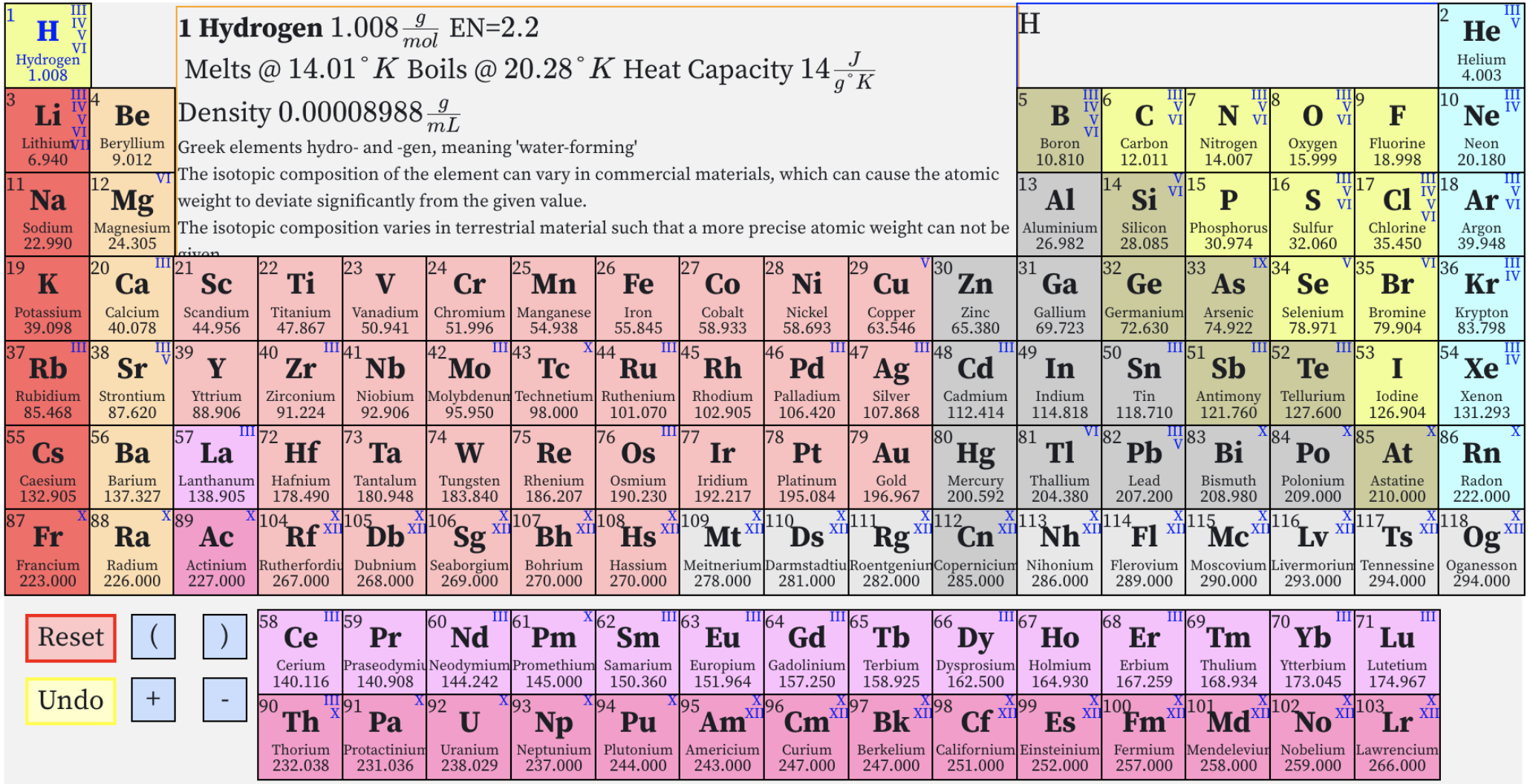


Fluorescent tube spectrum



Lab image of fluorescent tube spectrum

Questions 3 and 4: Spectra of the Elements



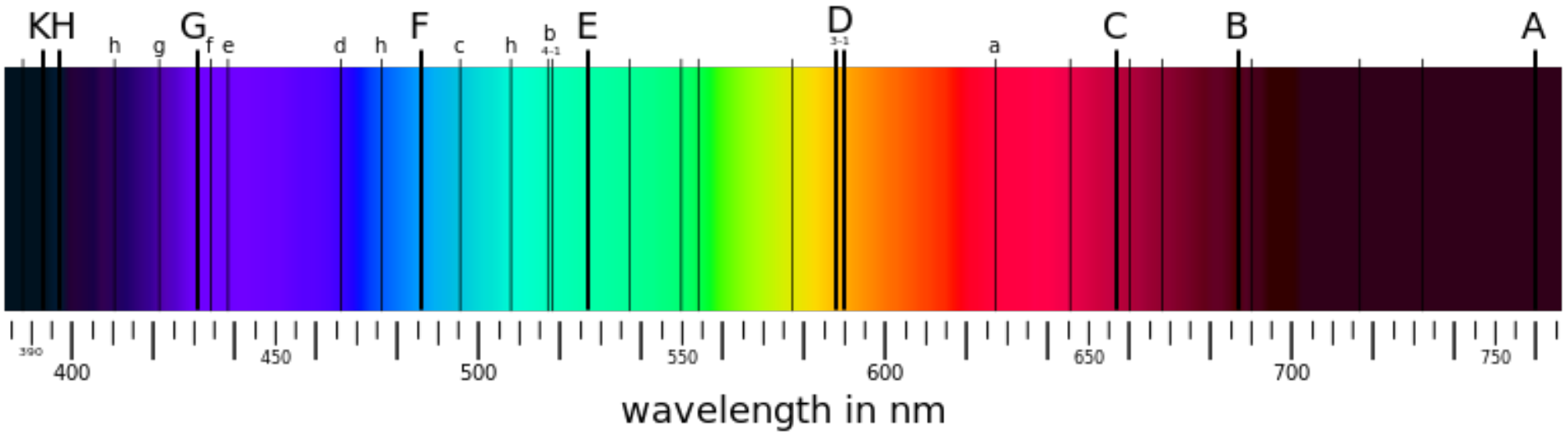
Play Hydrogen

https://observablehq.com/@mariodelgadosr/spectral-lines-of-elements-in-the-periodic-table

Spectral Lines for Hydrogen (H):

Question 5-7: The Solar Spectrum

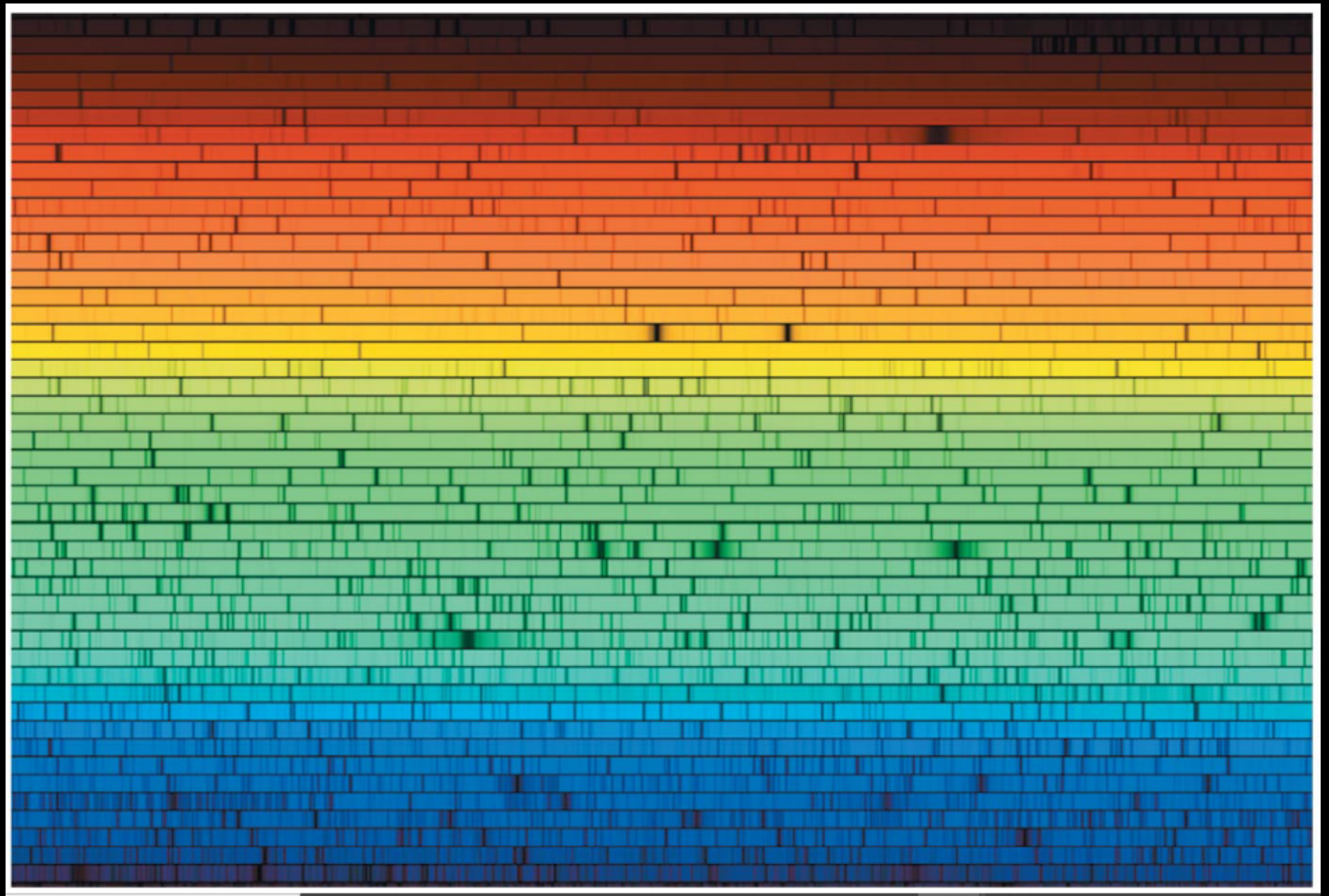
The Solar Spectrum



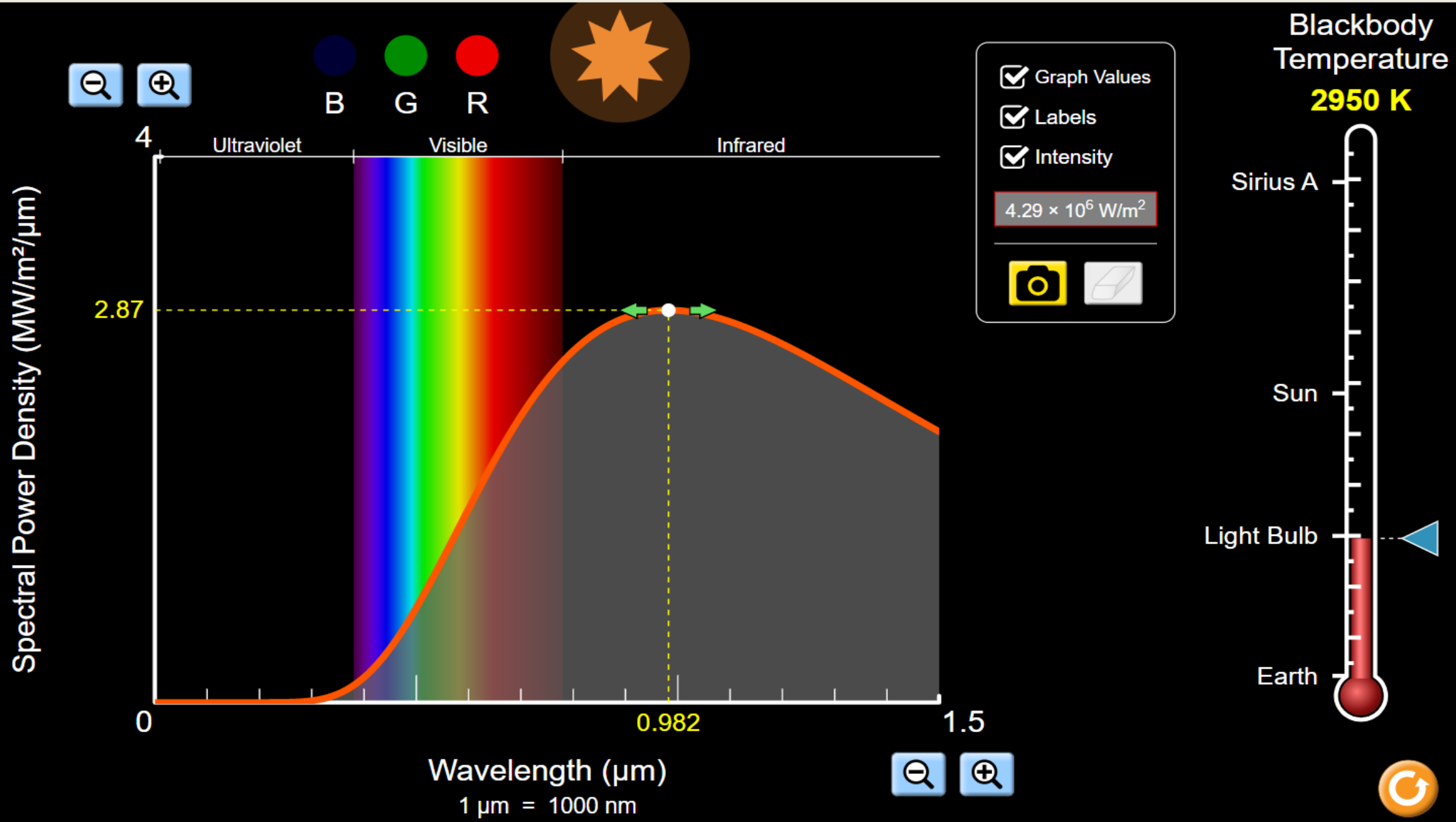
Designation	Element	Wavelength (nm)
y	O_2	898.765
Z	O_2	822.696
A	O_2	759.370
B	O_2	686.719
C	H_α	656.281
a	O_2	627.661
D1	Na	589.592
D2	Na	588.995
D3 or d	He	587.5618
e	Hg	546.073
E	Fe	527.039
b1	Mg	518.362
b2	Mg	517.270
b3	Fe	516.891
b4	Mg	516.733

Designation	Element	Wavelength (nm)
c	Fe	495.761
F	H_β	486.134
d	Fe	466.814
e	Fe	438.355
G'	Hγ	434.047
G	Fe	430.790
G	Ca	430.774
h	Hδ	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

Questions 5-7: The Solar Spectrum

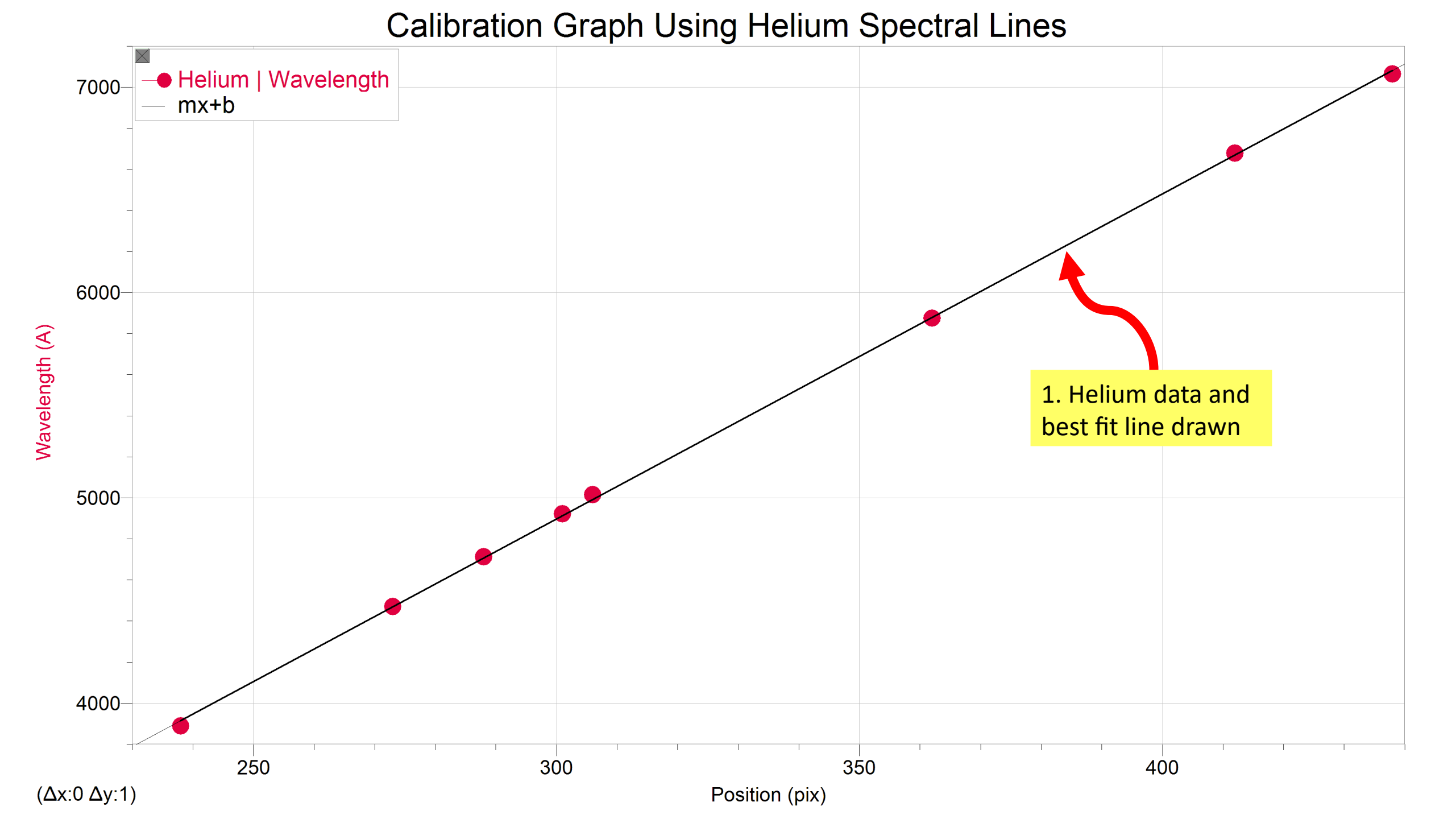


Question 8 - 12: Blackbody Spectrum



Part II: Measuring the wavelengths of the helium and hydrogen spectra.


[gimp-splash] (imported)-3.0 (RGB color 8-bit gamma integer, sRGB IEC61966-2.1, 1 layer) 1920x1080 – GIMP
File Edit Select View Image Layer Colors Tools Filters Windows Help
Tool Options
Crop
Current layer only
Allow growing
Expand from center
Fixed Aspect ratio
1920:1080
Position:
px
0
0
Size:
px
0
0
Highlight
Highlight opacity 50.0
No guides
Auto Shrink
Shrink merged
PORTABLE
GIMP 2.10
GNU IMAGE MANIPULATION PROGRAM
Mode Normal
Opacity 100.0
Lock:
gimp-splash.png
filter
2. Hardness 050 (51 × 51)
Basic,
Spacing 10.0
px 28.9 % gimp-splash.png (21.4 MB)


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