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Partner(s): ________________________
1102 or 3311: ______
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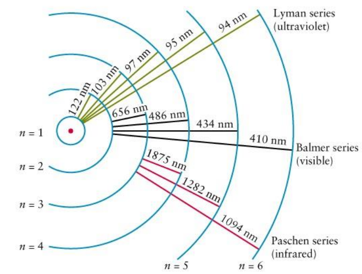


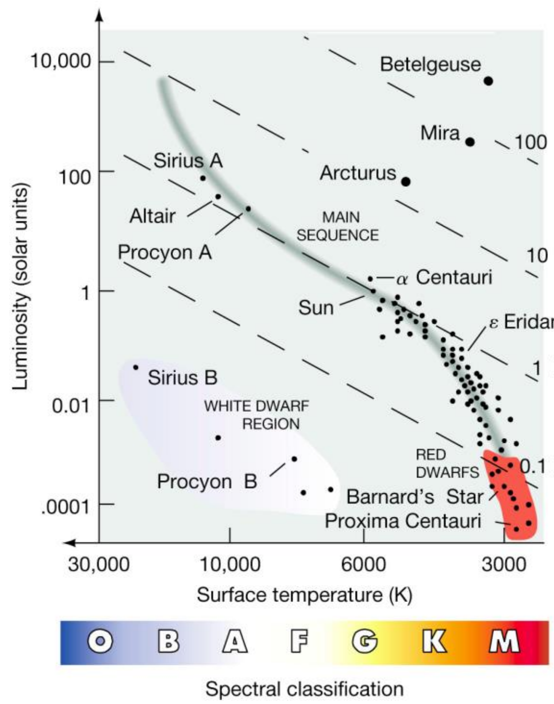
Spectroscopy Part II

Purpose: To study real stellar spectra and understand how astronomers define spectral classes of stars

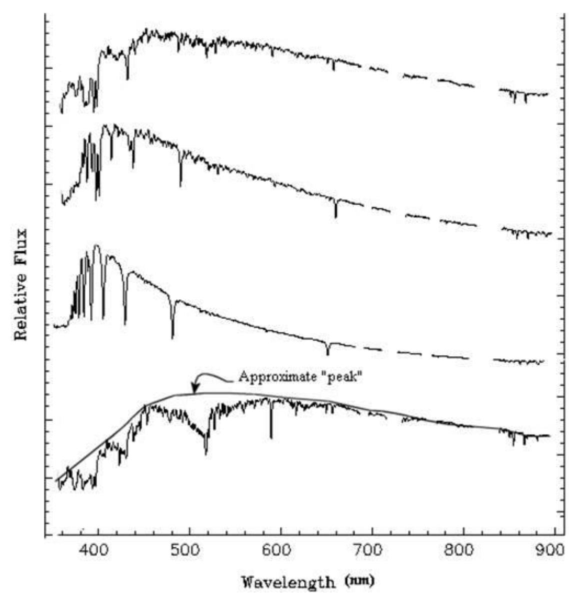
Preliminary questions: Use the following HR diagram to answer the following two questions. Notice the correspondence between the spectral class of a star (OBAFGKM) and the surface temperature.

a) If two stars are the same size, which is *brighter*, a red star or a blue star?

b) Estimate which color dominates the **visible** light of the following stars:
- Sirius B (25000 K)
- Sun (5800K)
- Betelgeuse (3000K)



Question 1: Guessing the surface temperature.
Here are 4 actual spectra from four different stars. Label the stars, Star A, Star B, Star C and Star D from the top down. Without calculations, list the stars from highest surface temperature to lowest surface temperature and explain why you chose that ordering.



Question 2: Calculating the surface temperature of a star. The wavelength of the peak of the blackbody curve λ_{peak}, can be calculated using Wien's Law. The peak wavelength is in nanometers and the surface temperature of the star is in Kelvin.

$$\lambda_{\text{peak}} = \frac{2.9\times10^6\,\text{K}\cdot\text{nm}}{T} \quad \text{or} \quad T = \frac{2.9\times10^6\,\text{K}\cdot\text{nm}}{\lambda_{\text{peak}}}$$

a) Fit by hand a blackbody curve to the spectra shown above of the stars A, B and C, like the curve on star D. Star D has the curve already drawn for you. The shape of the curve for this star was difficult to trace because of the deep absorption lines around 520 nm, probably due to molecules in the star. The deep absorption around 380 - 400 nm is due to singly ionized calcium.

b) Find the peak wavelength of each curve and calculate the corresponding temperatures.

Star A: Star C:

Star B: Star D:

Do your calculations agree with the predictions you made in Question 1?

c) How does the light that astronomers see from distant stars and galaxies tell them what they are made of? Why are spectral lines often referred to as "atomic fingerprints"?

d) Remember what you did in the previous spectroscopy lab. Distinguish among emission spectra, absorption spectra, and continuous spectra in how they look. (It's alright to use the word rainbow.)

e) **(ASTR 1102).** Distinguish among emission spectra and absorption spectra in how the spectra are *formed* physically—that is, what is going on in the atom. You can draw a diagram. If you do not know, have a look at Question 4.

Question 3: Identifying elements. Below are the spectra of three stars, Abba, Babba, and Cabba. They are made primarily of hydrogen and helium (just like all of the other stars in the sky). However, in this imaginary case, one star has a high percentage of carbon in its atmosphere, another has a high percentage of nitrogen, and the third has a high percentage of oxygen. Below these are 3 spectra of a number of different elements.

Star Abba

Star Babba

Star Cabba

Carbon (laboratory emission spectrum)

Nitrogen (laboratory emission spectrum)

Oxygen (laboratory emission spectrum)

Xenon (laboratory emission spectrum)

Hydrogen (laboratory emission spectrum)

Helium (laboratory emission spectrum)

a) Which star has a high abundance of nitrogen? Explain.

b) Which star has a high abundance of oxygen?

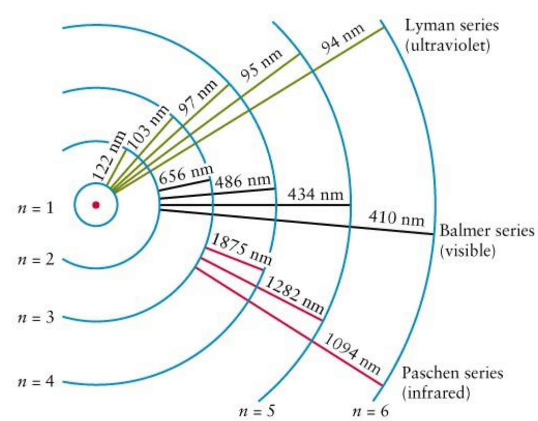
c) Which has a high abundance of carbon?

d) Do any of these three stars show evidence of having xenon in their atmospheres? Explain.

Question 4: The hydrogen atom. For many years, it was assumed that matter was made of small, indivisible, particles called atoms. Near the end of the nineteenth century, it was found that atoms were not indivisible, but contained both positive and negative particles. Nowadays, thanks to quantum mechanics, we do not describe electrons as particles any more. However, for the purpose of this lab, the particle model is sufficient.

We are mainly interested in the hydrogen atom. The symbol for hydrogen is H. Hydrogen is the simplest and lightest element in the universe. It consists of a proton and one electron in orbit around the proton. An electron can only occupy certain levels of energy.

<table>
<tr>
<td>When an electron moves from a higher to a lower level of energy, a photon is emitted.
- An electron moving from the third level to the second level emits a red photon (656 nm).
- An electron moving from the fifth level to the second level emits a blue photon (434 nm).

A hydrogen atom can also absorb a photon:
- A red photon at 656 nm will make a second level photon jump to the third level.
- A blue photon at 434 nm will make a second level photon jump to the fifth level</td>
<td>
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The electron transitions that correspond to the first level (from n = 1 to n = 2, 3, 4, 5, 6 …) is the Lyman series.
The electron transitions that correspond to the second level is the Balmer series.
The electron transitions that correspond to the third level is the Paschen series.

a) A hydrogen atom absorbs a photon at 103nm. What is the wavelength of this photon in Angstroms? (1 nm = 10 Angstroms) What is the colour of that photon?

b) Hydrogen atoms emit photons at 1282 nm. What kind of detector should you use to detect it (UV / Visible / IR)?

c) **(ASTR 1102 only):** What happens if an electron absorbs a photon with enough energy to place the electron above the highest possible energy level?

d) Complete with the range of the radiation (IR, UV or visible): An atom must absorb a/an

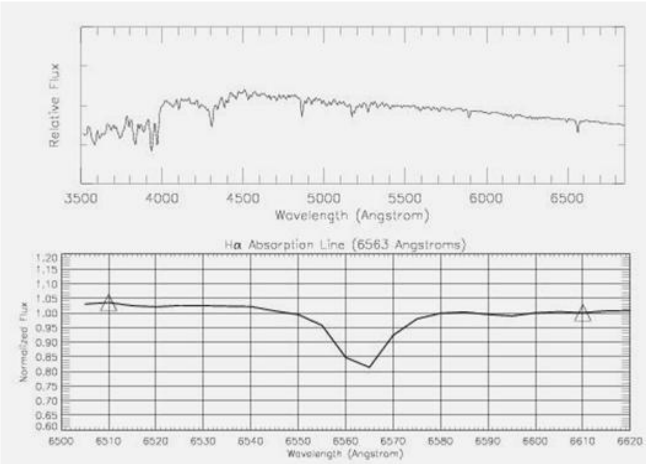
- ___________ photon to produce a Lyman series absorption line
- ___________ photon for the Balmer series
- ___________ photon for the Paschen series

Question 5: Spectral classification of stars. Look at the six panels of spectra on the next page (optical spectrum of six different stars). The top graph in each panel is the full spectrum; the bottom graph in each panel is a zoom-in of the Balmer series absorption line located at 6563 Angstroms. Astronomers call this particular absorption line H-alpha (because it is the first line in the Balmer series and alpha is the first letter of the Greek alphabet). Note the difference between the scale on the wavelength axis for the top and bottom graphs.

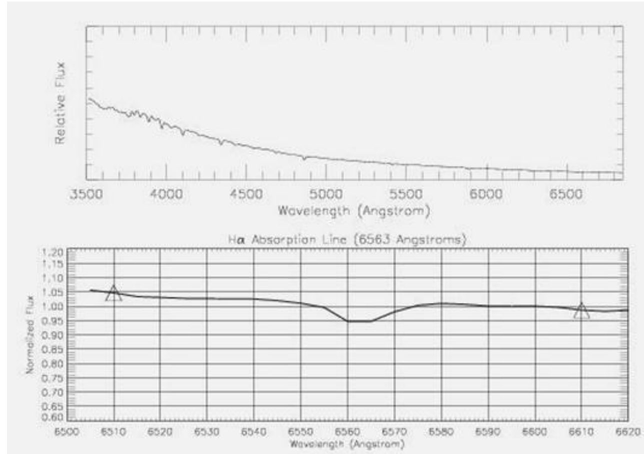
a) **(ASTR1102):** Why are the Lyman and Paschen series absorption lines not seen in each panel's spectrum?

b) In the top graph of each panel, circle ALL of the Balmer absorption lines.

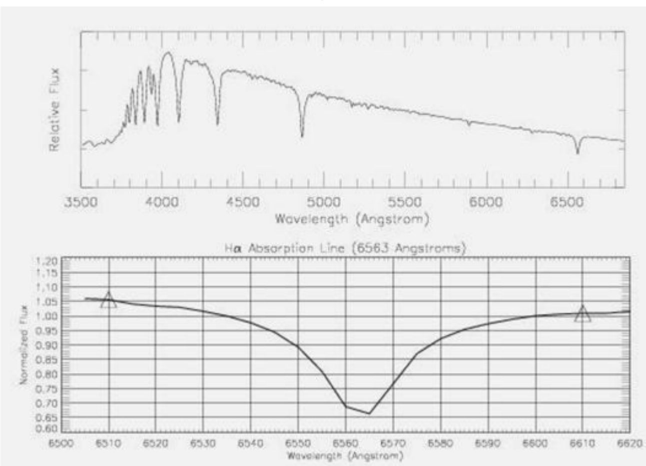
Panel 1



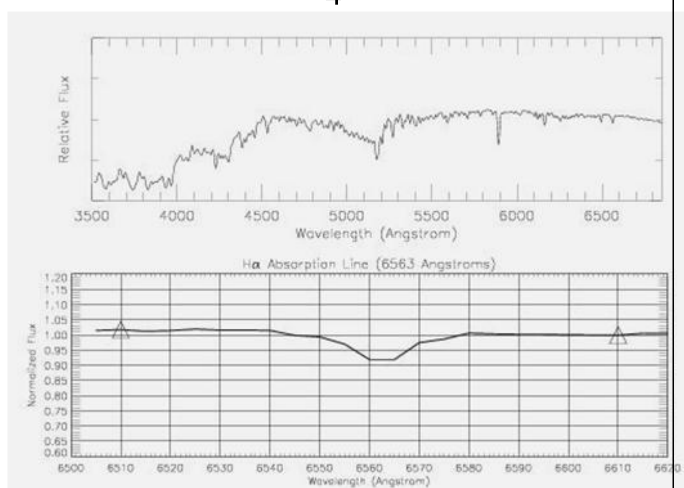
Panel 2



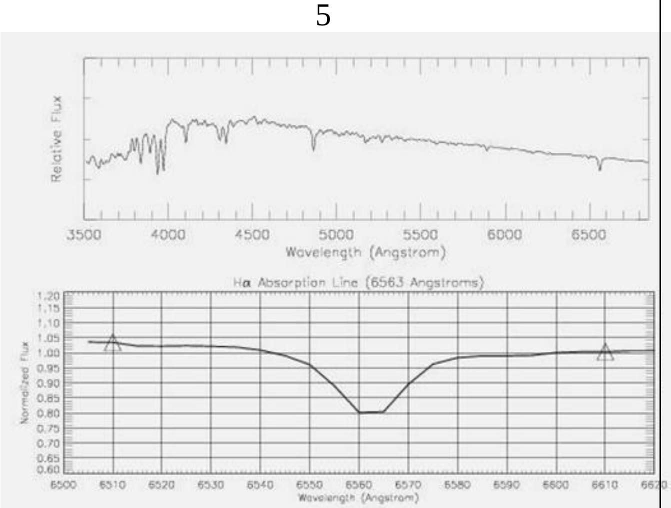
Panel 3



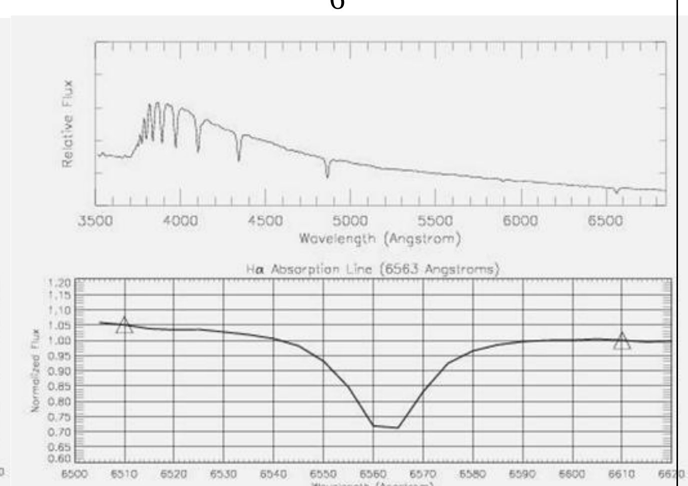
Panel 4



Panel 5



Panel 6



We are now going to classify stars based on the 'strength' of their H-alpha line, i.e. the area of the H-alpha line: it depends both on how much the line dips down and how wide it is. This is a practical example of numerical integration

c) Measure the strength of each H-alpha line by following this procedure:
- Draw a straight line in the bottom graph of each panel by connecting the triangles located at 6510 and 6610 Angstroms. You are tracing the continuum near the absorption line.
- Lightly shade in the absorption line now enclosed by the continuum.
- Measure the area enclosed in the absorption line by estimating the number of boxes inside of the line and keep a tally in the table below. For each line, total the number of boxes.
- Record the strength of the line in the table. (Add up the boxes.)

Table 1:

Panel	Strength of H alpha line (# of boxes) – Show box count (tally)
1	
2	
3	
4	
5	
6	

Originally astronomers classified those stars with the strongest hydrogen lines as 'A' stars, stars with the next strongest lines as 'B' stars, the next strongest 'C' and so on. Eventually some letters were deemed unnecessary and dropped from the classification sequence. The letter assigned to a star is termed its spectral class.

d) Assign a spectral class to each panel by following this procedure:
- List the panel numbers from strongest H alpha line to weakest H alpha line.
- Fill in the last column with A, B, F, G, K and O (in that order since we’ve already sorted in decreasing hydrogen line strength.

Table 2:

	Panel Number	Class
1st strongest		
2nd strongest		
3rd strongest		
4th strongest		
5th strongest		
6th strongest		

Question 6: Classification of stars and effective temperature. In Question 2, you determined the surface temperature of some stars (i.e. the temperature of each star's photosphere) using the full spectrum and Wien's Law. Let's do this again.

a) Using Wien's Law, determine the surface temperature of the 6 stars using the top graph of each panel on page 6.

Table 3:

Panel	Peak Wavelength (Angstroms)	Temperature (K)
1		
2		
3		
4		
5		
6		

It was later realized that the strength of a star's absorption lines can be predicted if the star's surface temperature is known. This is because the heat of a star can excite electrons up to higher energy levels. For example, most hydrogen atoms in very hot stars are ionized (the electron leaves the atom completely,) and thus show very weak Balmer Series absorption lines. Cool stars keep most of their electrons in the 1^{st} energy level.

Conclusion: Medium temperature stars show the strongest Balmer lines because most of their electrons start in the 2^{nd} energy level.

Astronomers reordered the classification sequence such that the hottest stars came first, but they retained the letters originally assigned to each star based on their Balmer line strengths.

b) Reorder the classification sequence by listing the panels from hottest star to coolest star.
c) Write down the letter you assigned to each panel from Table 2.

Table 4:

Panel Number (hottest to coolest)	Panel Class from Table 2 (ABFGKO)

Question 7: Discussion.

a) Explain why the Stellar Classification Sequence is not in alphabetical order.

In addition to the 6 spectral types studied in this lab (ABFGKO), stars classified as L, M and T also exist. L, M and T stars are all cooler than K stars, with M stars being the hottest of the three and T stars the coolest.

b) Rewrite the classification sequence you found in Table 4 to include L, M and T stars.

The following questions are for ASTR1102 only:

c) What energy level must most hydrogen electrons start on to show Balmer absorption lines?

d) What spectral class has the strongest Balmer lines? What temperature does this correspond to?

e) Why do the hottest stars show weak Balmer lines?

f) Why do the coolest stars show weak Balmer lines?