Absorption Line Activity
(Teacher's Guide)

Purpose: Demonstrate how absorption lines happen and how scientists use absorption lines to determine the composition of a star

Materials:

- 12 colored marbles (any other type of small colored object will work)
  - 3 green, 3 blue, 3 red, 3 yellow (the specific colors used are not important)
- Opaque bag big enough to easily fit the 12 marbles
- 3 student volunteers

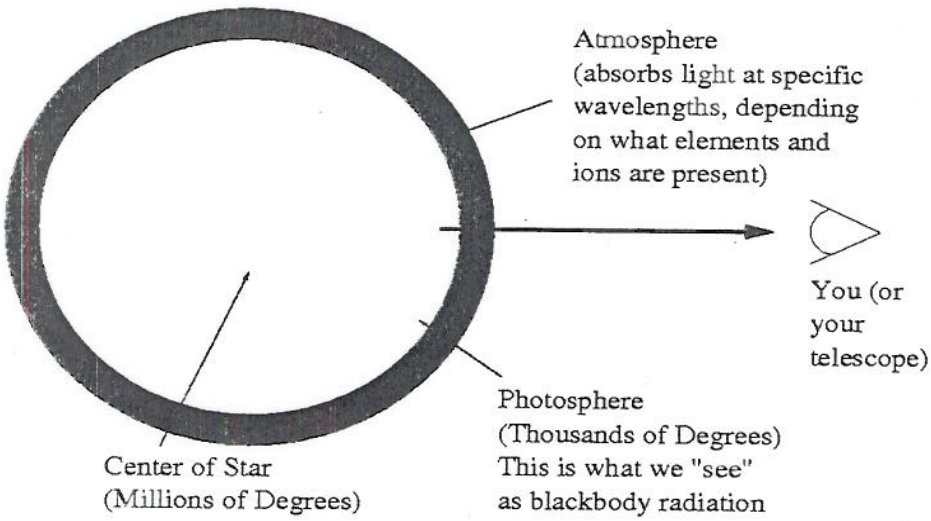
Procedure:

- Select 3 student volunteers.
- Line the students up at the front of the classroom.
  - Show that there are 12 colored marbles in the bag, 3 of each color.
  - Announce that you (the teacher) will walk by the volunteers. You will not stop walking, and each student volunteer can remove just one marble of their favorite color from the bag. *Once they choose a specific color marble, they MUST choose that same color marble for the rest of the activity!* The volunteers should NOT show anybody what color marble they chose.
- Walk by the volunteers and have them choose their marbles. When you pass all 3 volunteers, look inside the bag and determine what marbles remain.
  - By doing this, you can tell what marbles are missing since we know what marbles we started off with.
- BUT, we want to know which marble each specific student has.
  - Ask the class how we can determine what color marble each student chose.
    - If nobody mentions it, suggest isolating each person so the marble they remove is the **only** marble removed.
- This time, walk by each volunteer separately and have them remove their favorite color marble
  - From this we can determine the specific color marble each person takes.
    - Write each volunteers name on the board and the corresponding color marble they choose.
- So, now that we know what color marble each person likes. By looking at the remaining marbles, the exact people removing marbles can be determined!
  - If the students do not understand this yet, wait until after we relate this to stars to explain it more.
- Now, relate this to stars. Define a location where the star is shining from and a location from where the observer is viewing the star's light (where the telescope would be).
  - Possibly draw a big star on one side of the room and a big eyeball, or telescope, on the other side of the room.

- The students must be standing between the star and the observer.

- Announce that the marbles represent light – different color marbles mean different wavelength of light. The students represent different gases in the atmosphere of a star.
- So, we already know what color marble each volunteer likes. And since the volunteers now represent gases, we know what color marble each specific gas likes!
- Now, pretend that we do NOT know which gases (volunteers) are between the star and the observer.
- Walk the marble bag from the star to the observer.
  - See what marbles are missing and determine the gases (volunteers) are between the star and the observer. This is easy because we basically just did it. *Be sure to explain how the missing marbles are the absorption lines.*
- Now, select 4 new volunteers. Have the previous 3 volunteers go back to their seats.
  - Assign each new student one of 4 gases (hydrogen, helium, carbon, and oxygen work well) and the color marble they like. Each gas should like a different color – 4 gases, 4 colors. Write this information (person, gas, marble color) on the board for everybody to see.
- Arrange the 4 volunteers in scattered positions between the star and the observer. Announce that you (the teacher) will walk by either 1, 2, 3, or all 4 of the students on your way from the star to the observer.
- Instruct the students sitting at their desks to close their eyes while you (the teacher) walk from the sun to the observer.
- When you (the teacher) get to the observer, tell everyone to open their eyes and show them the remaining marbles. Find out what marbles are missing and determine what gases you (the teacher) walked by.
- Be sure to tie this all together well and explain how this represents stellar absorption lines. The picture below shows the star, the star's atmosphere, and observer.

Star, Stellar Atmosphere, and Observer (not to scale)

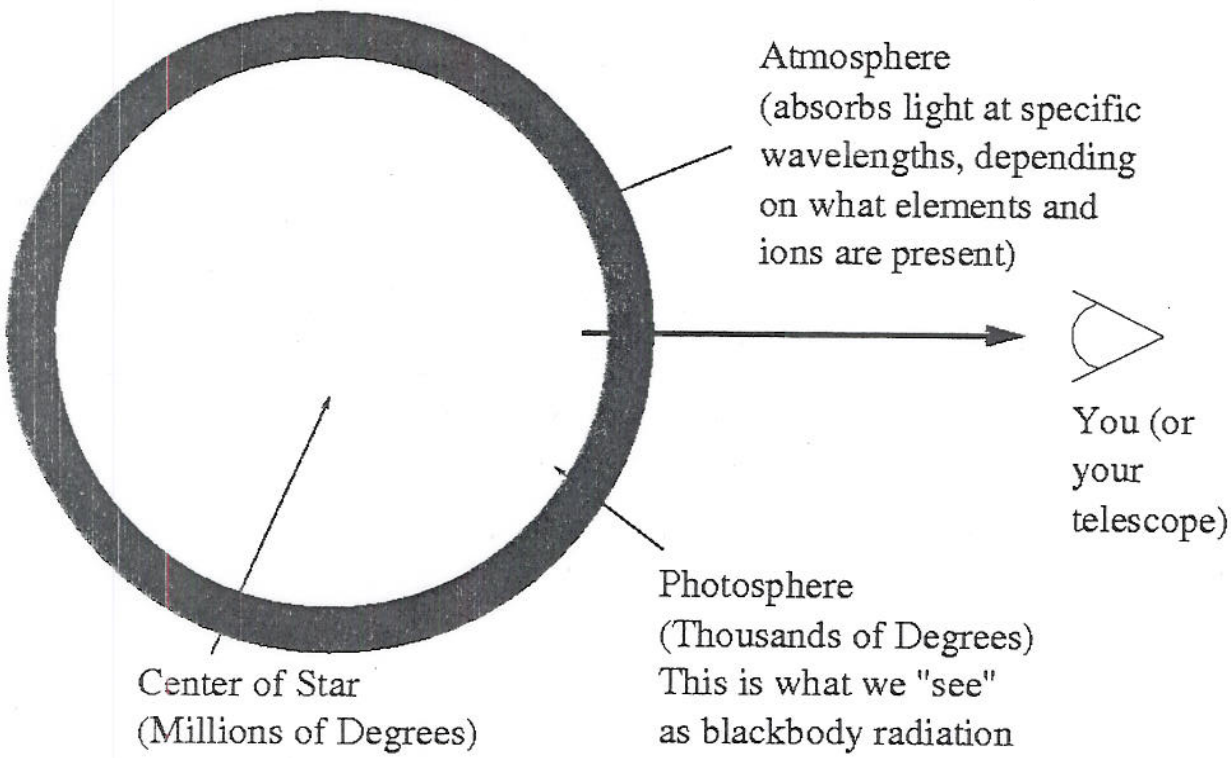


Congratulations! You have just demonstrated how absorption lines happen and how scientists use absorption lines to determine the composition of a star.

Absorption Lines

A "pure" blackbody has a smooth spectrum, but the stellar spectra have absorption lines. This is because of the star's atmosphere. It blocks out light at specific wavelengths. The wavelengths that are blocked cause absorption lines in the spectrum. Each element blocks light at different wavelengths. Let's see how this works.

Star, Stellar Atmosphere, and Observer (not to scale)

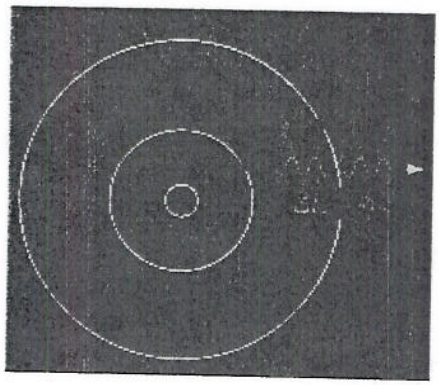


Atoms are electrons orbiting around a nucleus. The farther an electron is from the nucleus, the more energy it has. It's astonishing that electrons can have only certain energy levels – the energy is quantized. Just like an elevator can stop on the first floor or second floor, but not on the 9¾ floor, the laws of quantum mechanics only allow electrons to be at specific well defined energies.

To move from a lower floor to a higher floor, an atom needs to gain energy by absorbing a photon that has exactly the energy it takes to get it to its new floor. Similarly, when an electron falls from a higher floor to a lower floor, it emits a photon that has exactly the amount of energy. The key point is that the wavelength of the light (which is related to its energy, $\Delta E=hc/\lambda$) tells us the energy difference.

All hydrogen atoms have the same energy levels. Helium atoms have different energy levels than hydrogen, but all helium atoms have the same energy levels as other helium atoms. A helium ion (which is missing one electron) has another set of energy levels. So, the pattern of energy level differences uniquely identifies the atom or ion.

For example, let's look at hydrogen.



The Balmer Series are called H_{alpha}, H_{beta}, H_{gamma}. The Balmer Series are the transitions that happen when an electron falls to the 2nd floor from a higher floor. H_{alpha} is when the electron falls from the 3rd floor to the 2nd floor, H_{beta} is 4 to 2, H_{gamma} is 5 to 2, and so on. It's convenient for astronomers to remember the wavelength of light associated with these levels of differences because that is the wavelength of light that is either emitted when the electron falls to the first floor or is absorbed when the electron moves from the first floor up to a higher floor.

Just like you remember phone numbers of your friends, you will remember the wavelengths. Let's look at the Balmer Series.

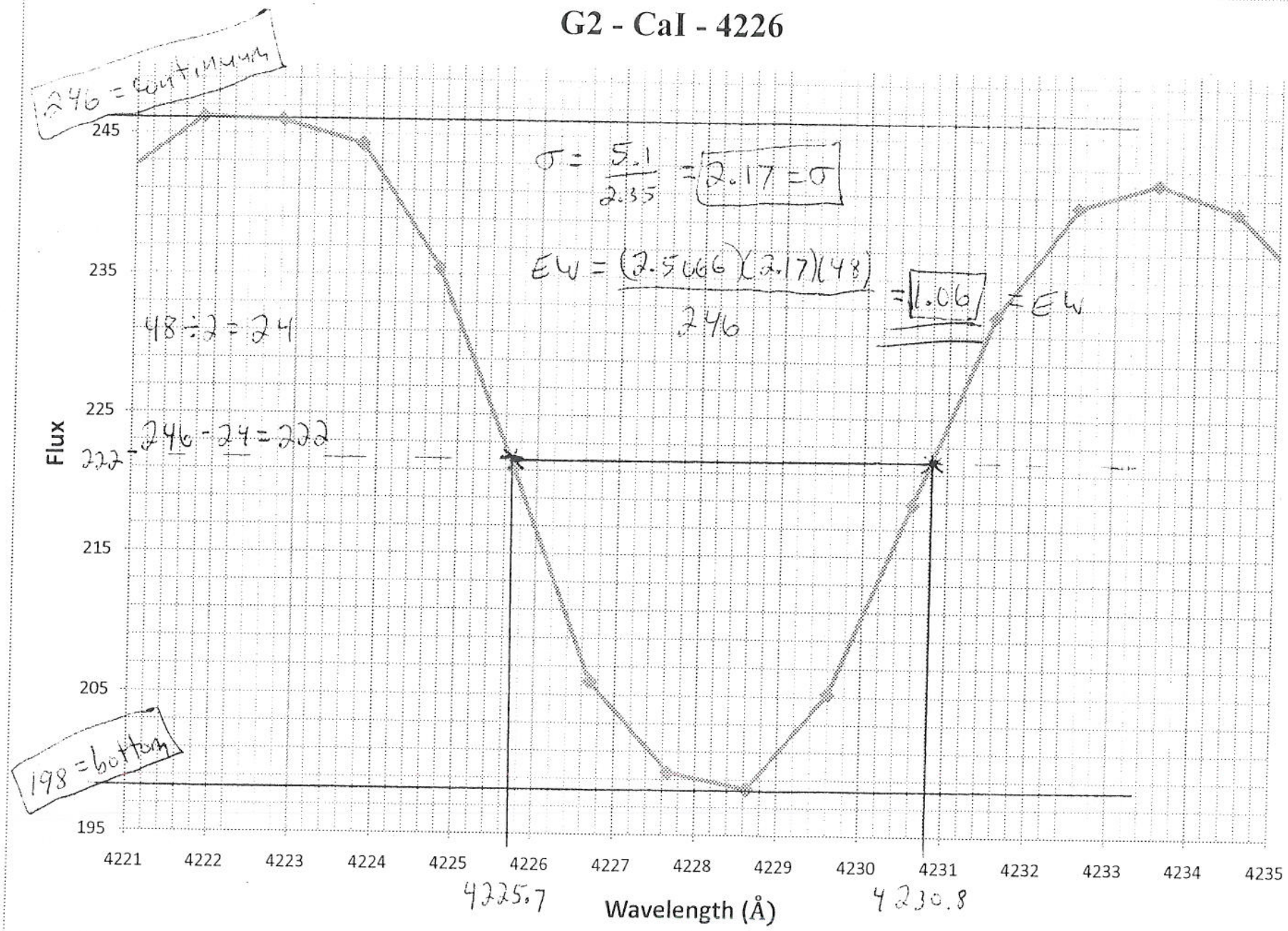
Balmer Series	
H_{alpha}	6565 Å
H_{beta}	4863 Å
H_{gamma}	4342 Å
H_{delta}	4103 Å

Each specific element has specific wavelengths of light that they like. If this specific wavelength of light hits that element, it will get absorbed by the element, leaving a gap in the spectrum at that wavelength. These absorption lines are very interesting and tell us what element is present, how much of it there is, and the gas pressure.

There are other lines, we'll get to those. Hydrogen is the strongest line and in many stars the most obvious. But, lots of other elements, some as heavy as iron, can appear in stellar spectra and give us important clues about the star.

Below is a "telephone book" listing the wavelengths of some important elements; Hydrogen has several different wavelengths called the Balmer series, which is very useful in stellar classification. We will use these wavelengths to determine what we can find in any given spectrum.

G2 - CaI - 4226



height = 246 - 198 = 48 = height

FWHM = 4230.8 - 4225.7 = 5.1 = FWHM

Wavelength (Å)	Label (what it is)
3934.777	Ionized Calcium (K)
3969.588	Ionized Calcium (H)
4102.89	Hydrogen-delta(H_δ)
4200	Neutral Helium (He)
4341.68	Hydrogen-gamma (H_γ)
4400	Ionized Helium (He^+)
4862.68	Hydrogen-beta (H_β)
4900-5200, 5400-5700, 6200-6300, 6700-6900	Titanium Oxide (TiO)
5176.7	Mg
5895.6	Sodium (Na)
6564.61	H-alpha (H_α)
8500.36, 8544.44, 8664.52	Ionized Calcium (CaII)

We have learned that by looking at how far along the x-axis an absorption line occurs at we can tell what it is. If we look at how big (the area) the absorption line is, we can find out how much of the element is present. Finally, the width of the absorption line tells us the gas pressure. This is used in the Yerkes, or MKK, system.

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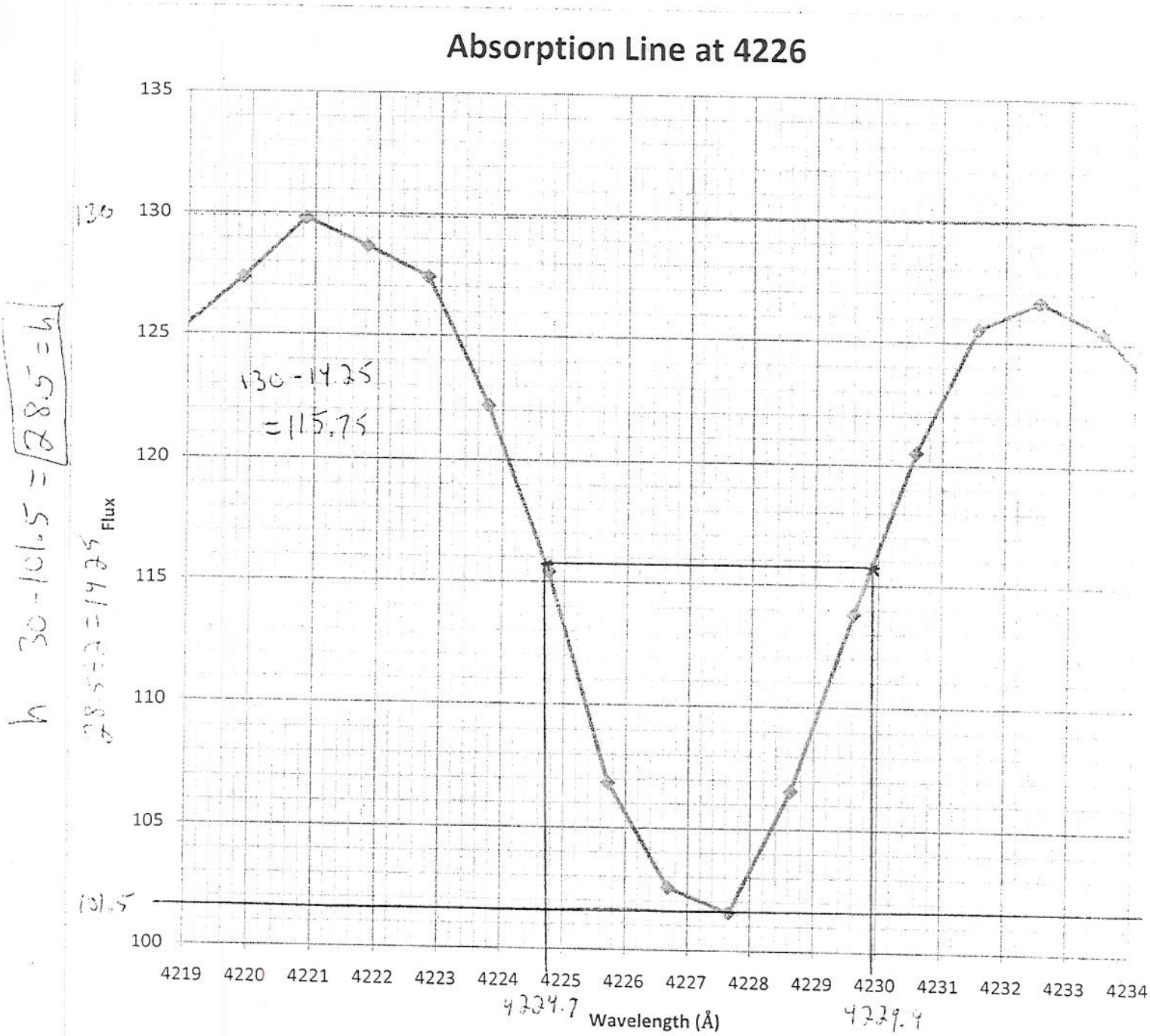


$4229.9 - 4224.7 = 5.2 = FWHM$

$\sigma = \frac{5.2}{2.35} = 2.213$

$EW = \frac{(2.5066)(2.213)(28.5)}{130} = \boxed{1.22\ Å}$

Name: _____ Date: _____ Period: _____

Equivalent Widths

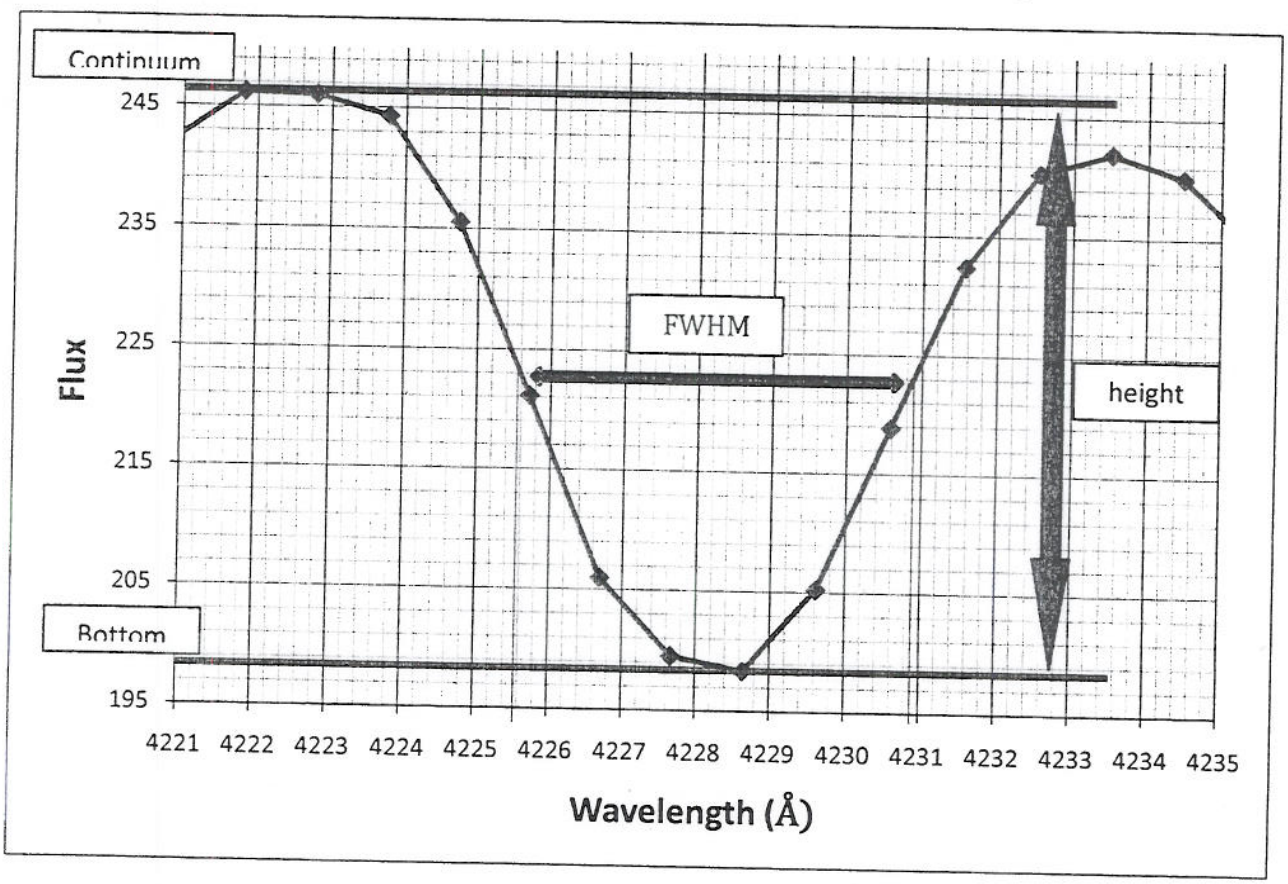
The two pictures below are graphs of important absorption lines from the spectrum of a F8, G0, or G2 star. Calculate the equivalent widths of the two absorption lines below. Then, use the information provided about star classification and ratios of equivalent widths to classify the star.

$$\sigma = \frac{FWHM}{2.35}$$

$$EW = \frac{2.5066 * \sigma * height}{continuum}$$

FWHM = Full Width Half Maximum. The flux for $FWHM = continuum - \frac{height}{2}$. Once the flux is found, FWHM is the distance between the curve at that flux, measured in angstroms.
EW = Equivalent Width, measured in angstroms
Height = continuum - bottom

Star Classification	Ratio of 4226:4342
F8	0.4
G0	0.5
G2	0.65



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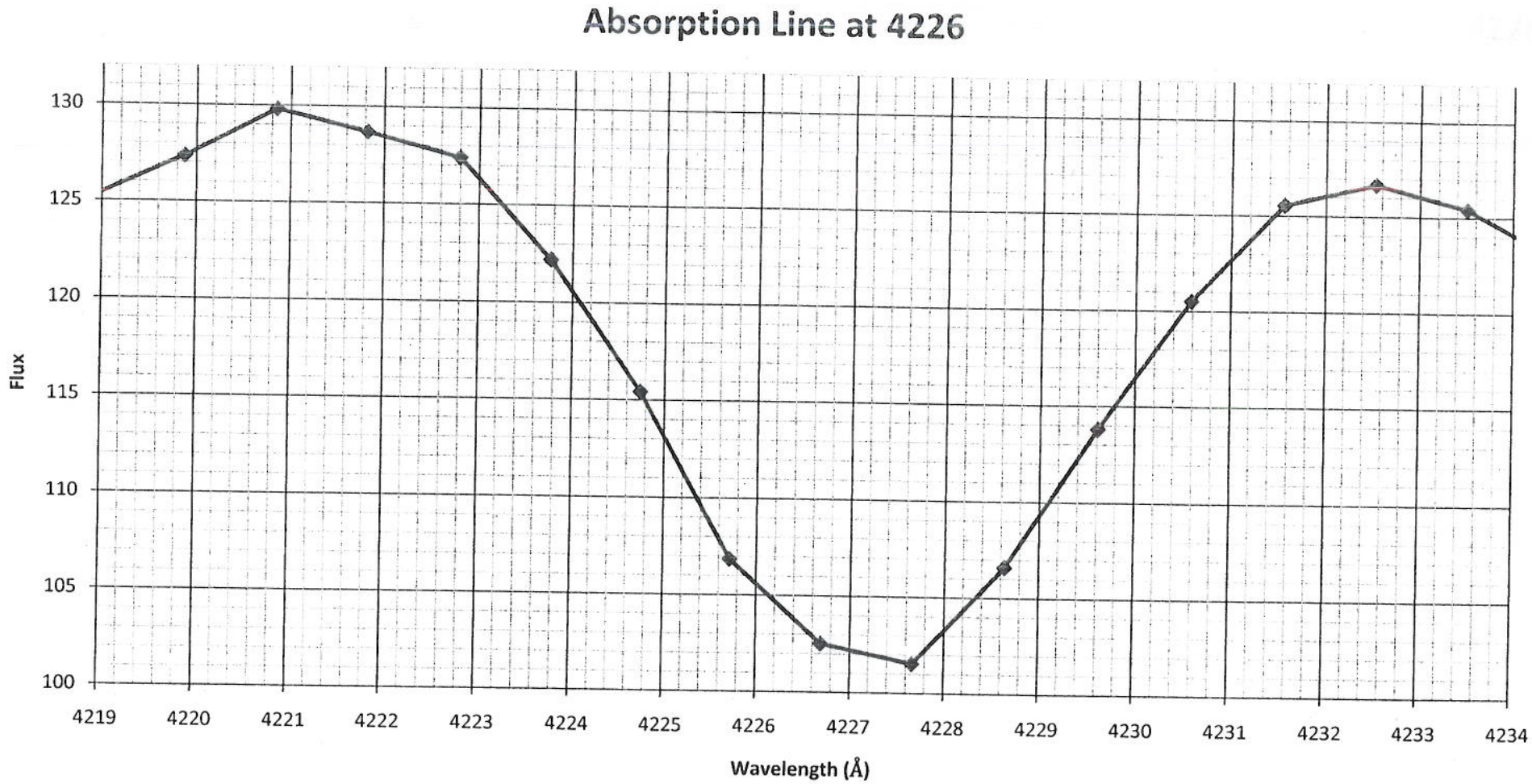

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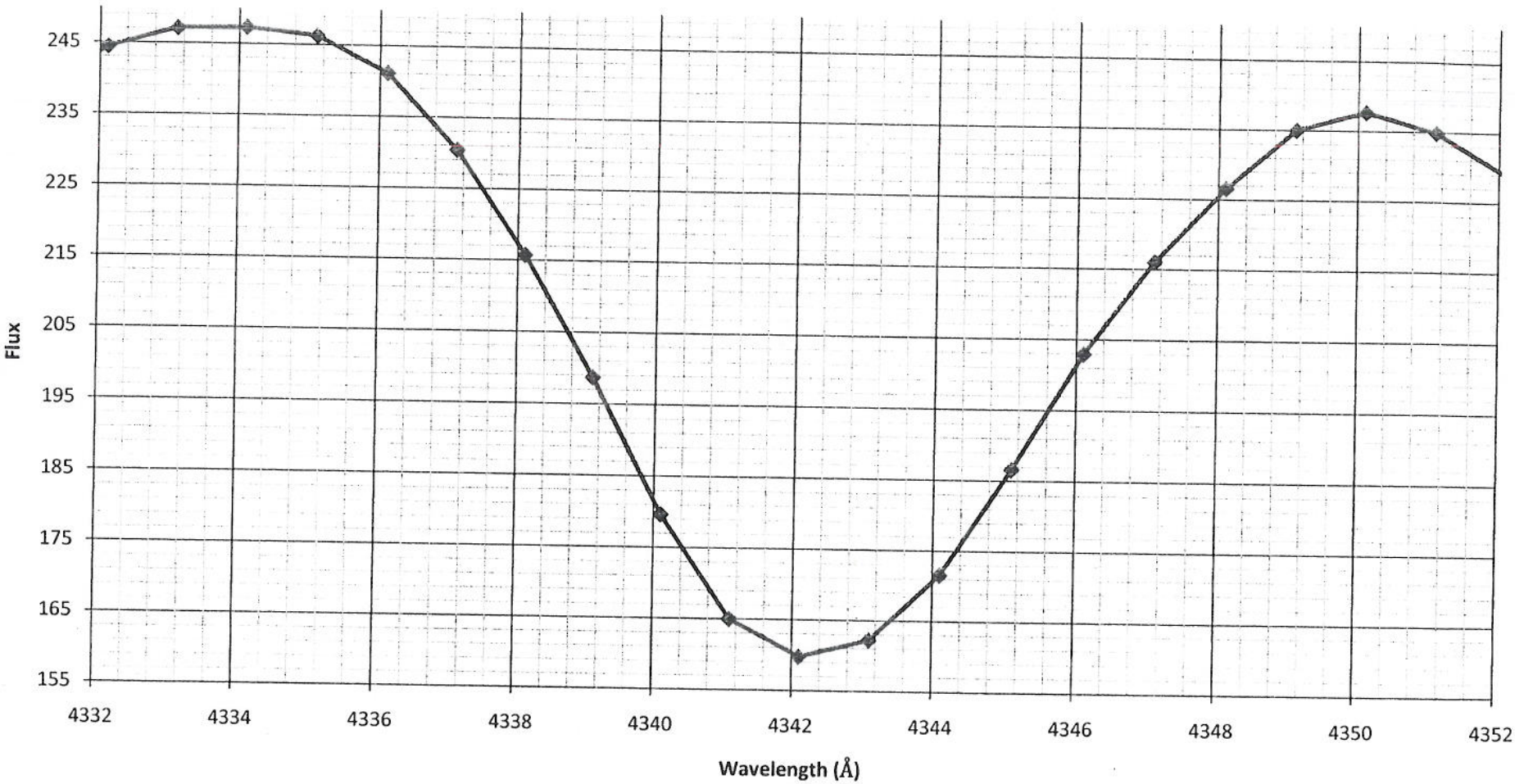
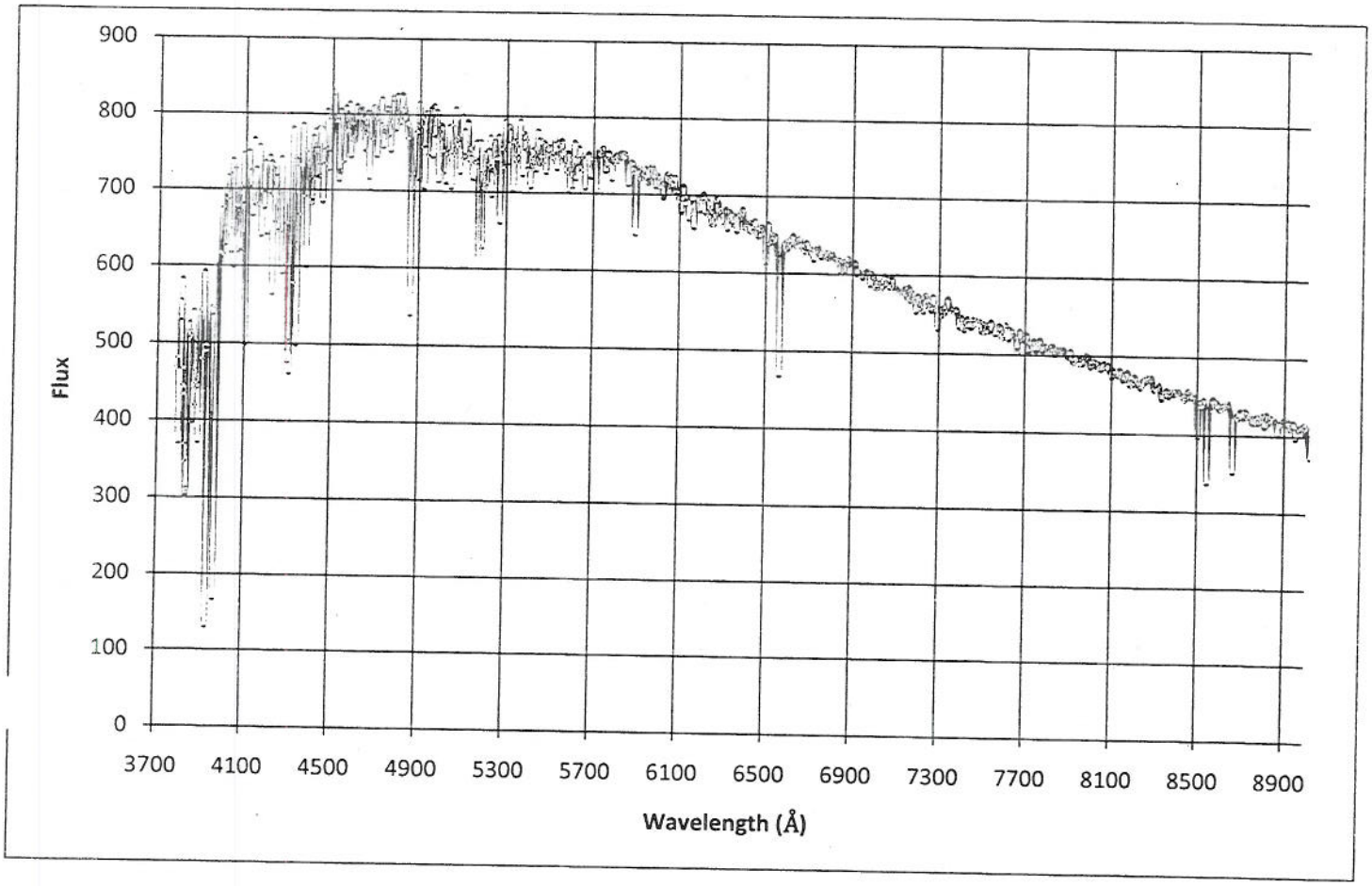
Absorption Line at 4342



Station 1

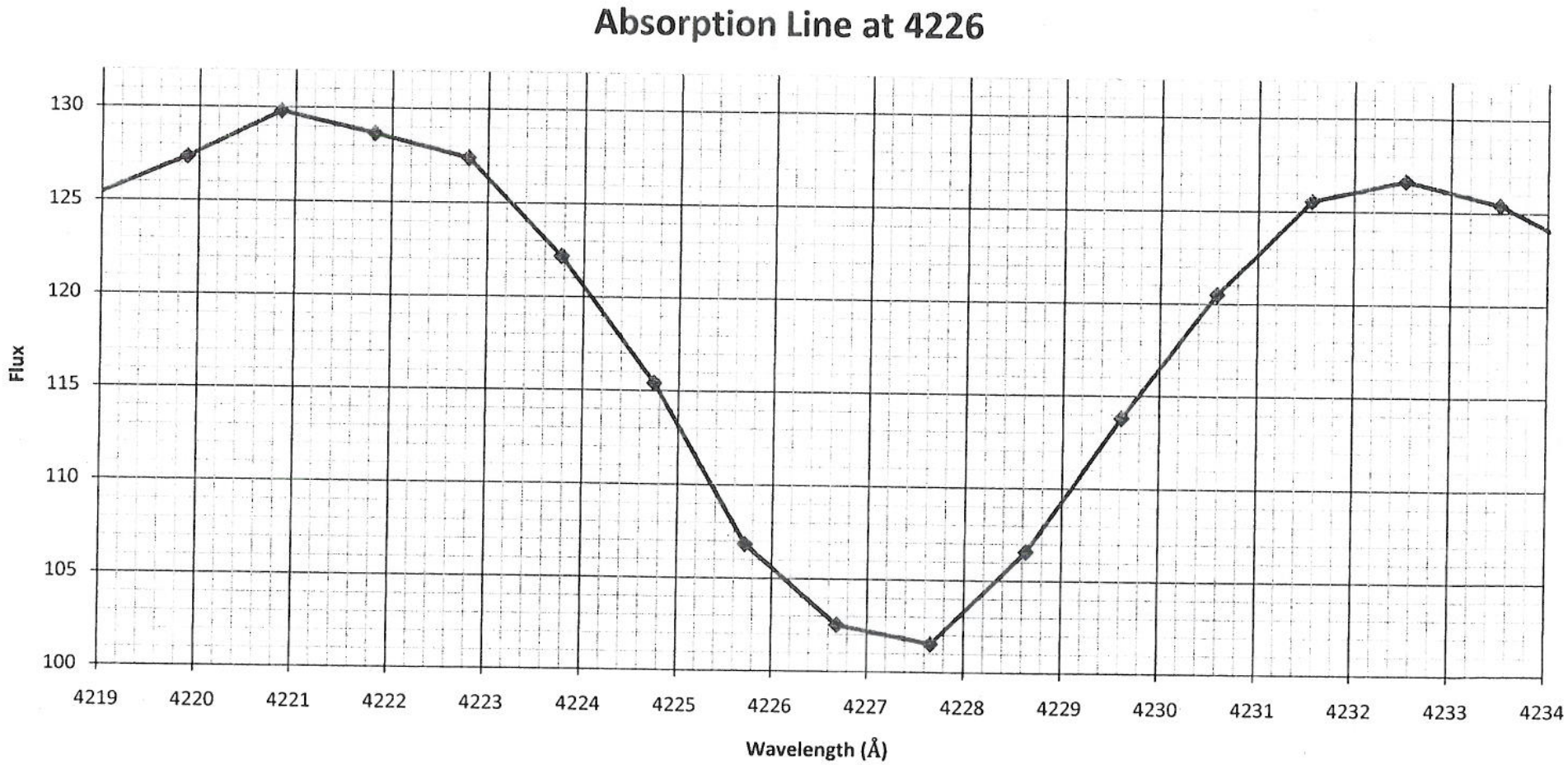
Using Wein's Law, calculate the temperature of the star with the spectrum shown below. Use this temperature to classify the star. Give the star both a spectral type AND a subtype. Ex: Our sun is a G2.



Station 2

Calculate the equivalent width of the following absorption line and then classify the star. The absorption line of this same star at 4342 angstroms was measure to be 3.05Å.

Star Classification	Ratio of 4226:4342
F8	0.4
G0	0.5
G2	0.65



Station 3

What is an absorption line?

What is an emission line?

How are they similar?

How do they differ?

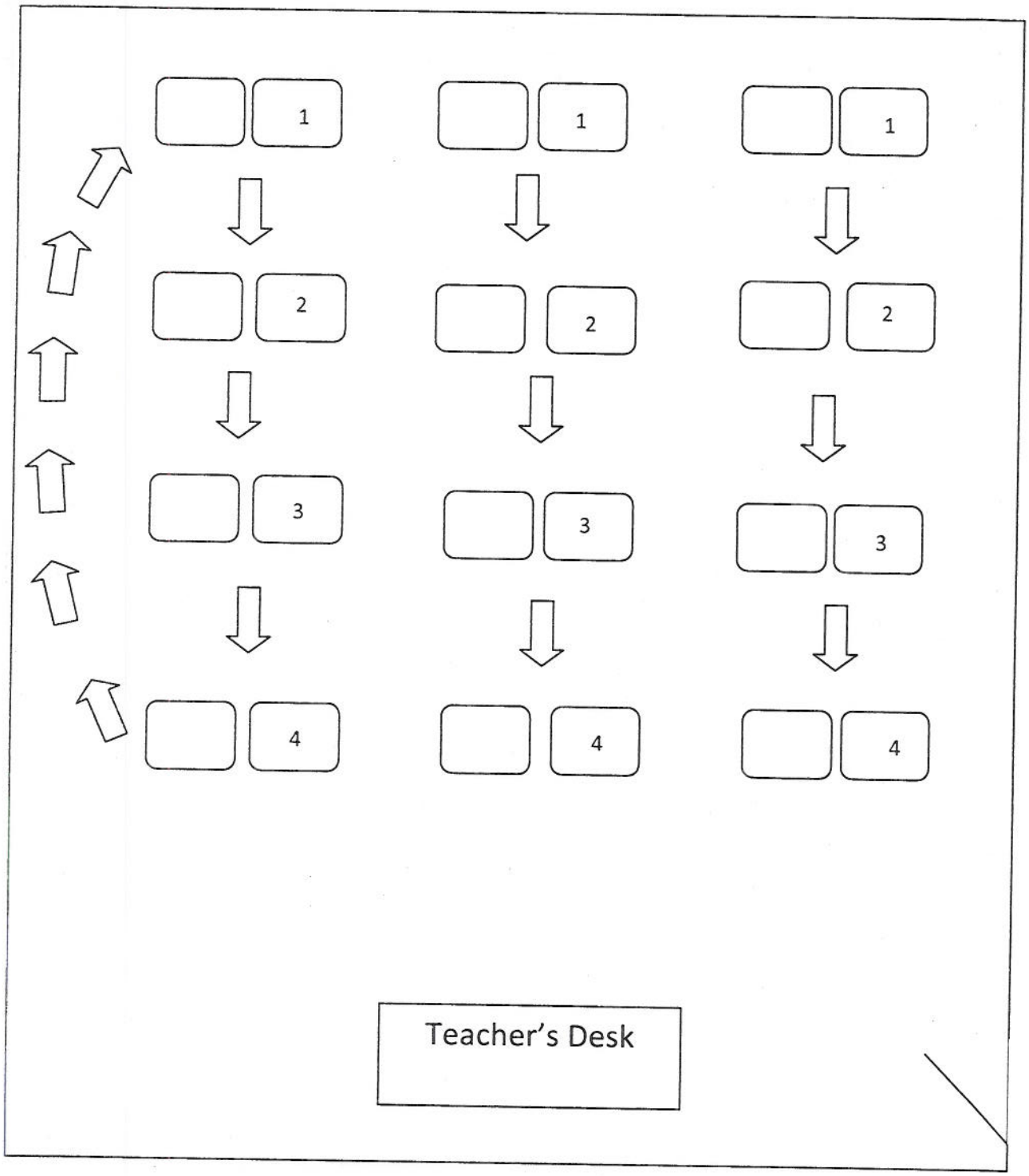
Station 4

Remember when we looked at the spectra of various light sources with our spectroscope. What is/are the limitation(s) of the spectroscope we used?

How would we improve the limitations?

Group Problem Solving Guide

The number represents which problem sheet is at which station. The arrows represent the direction the students move when it is time to move to the next station.



Name: _____ Date: _____ Period: _____

Stars Unit Exam

True or False

Read the following statements and determine if they are true or false.

1. True False White light is a mixture of all colors.

2. True False The spectra of all white light appear identical.

Short Answer

Please use complete sentences in your responses.

3. When we looked at various light sources with our spectroscopes, there was a limitation to what we could see. Why are digital spectroscopes a better tool for classifying stars?

4. How can scientists use the fact that stars emit electromagnetic radiation to determine the composition of a star? Be as specific as possible.

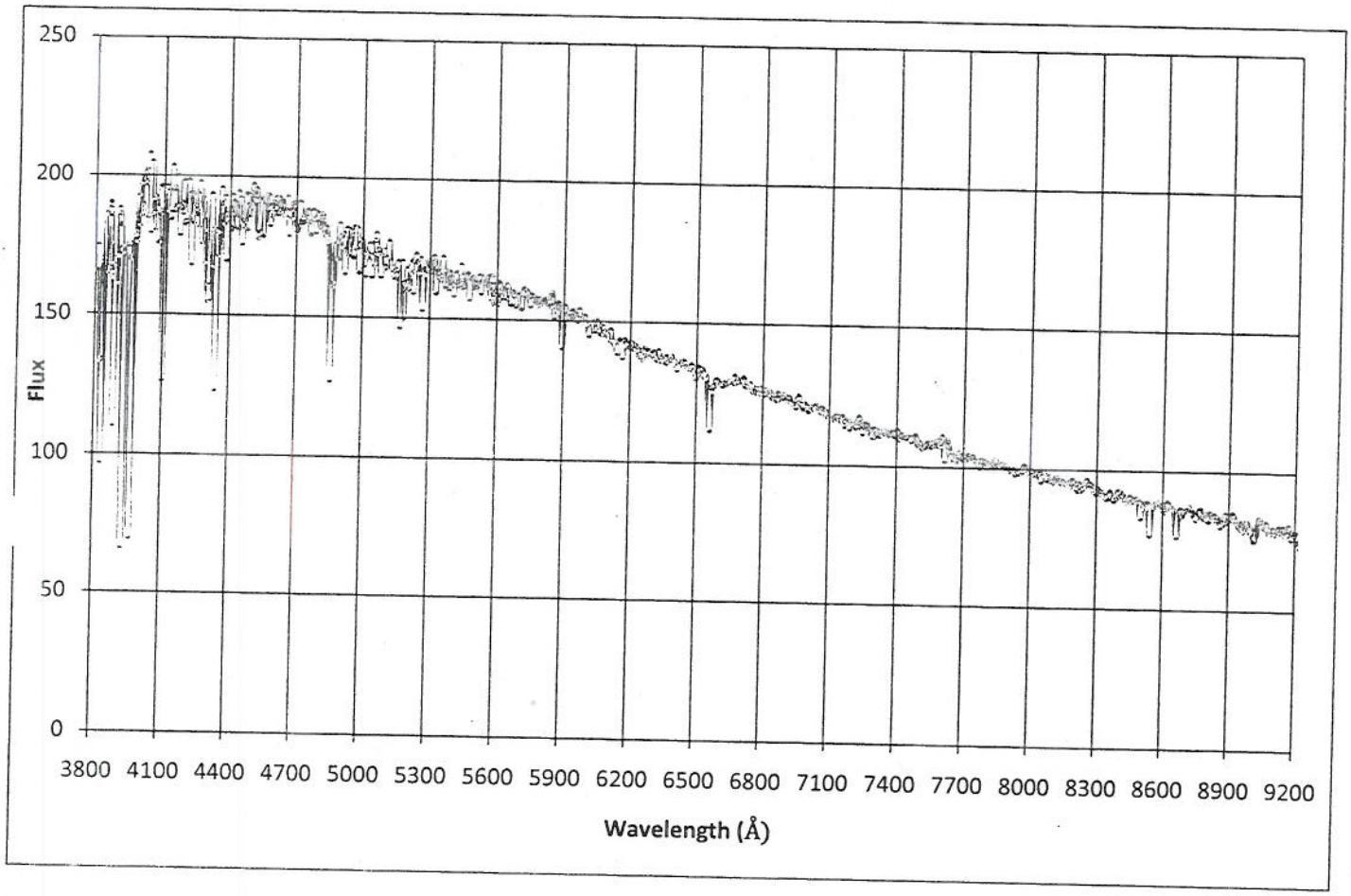
Name: _____ Date: _____ Period: _____

Calculation

Show *all* of your work in your calculations to receive full credit.

5. Using Wien's Law, assign a spectral type (OBAFGKM) to the star with the following spectrum. No subtype (number after the letter) is necessary.

$$\lambda_{peak} = \frac{b}{T} \qquad b = 2.9x10^{-3} m \cdot K$$



Name: _____ Date: _____ Period: _____

6. The picture on the following page is a graph of an important absorption line from a star. Using what you have learned about classifying stars based on their absorption line ratios, classify this star as either an F8, G0, or G2 star. The equivalent width at 4342 was measured to be 1.87Å.

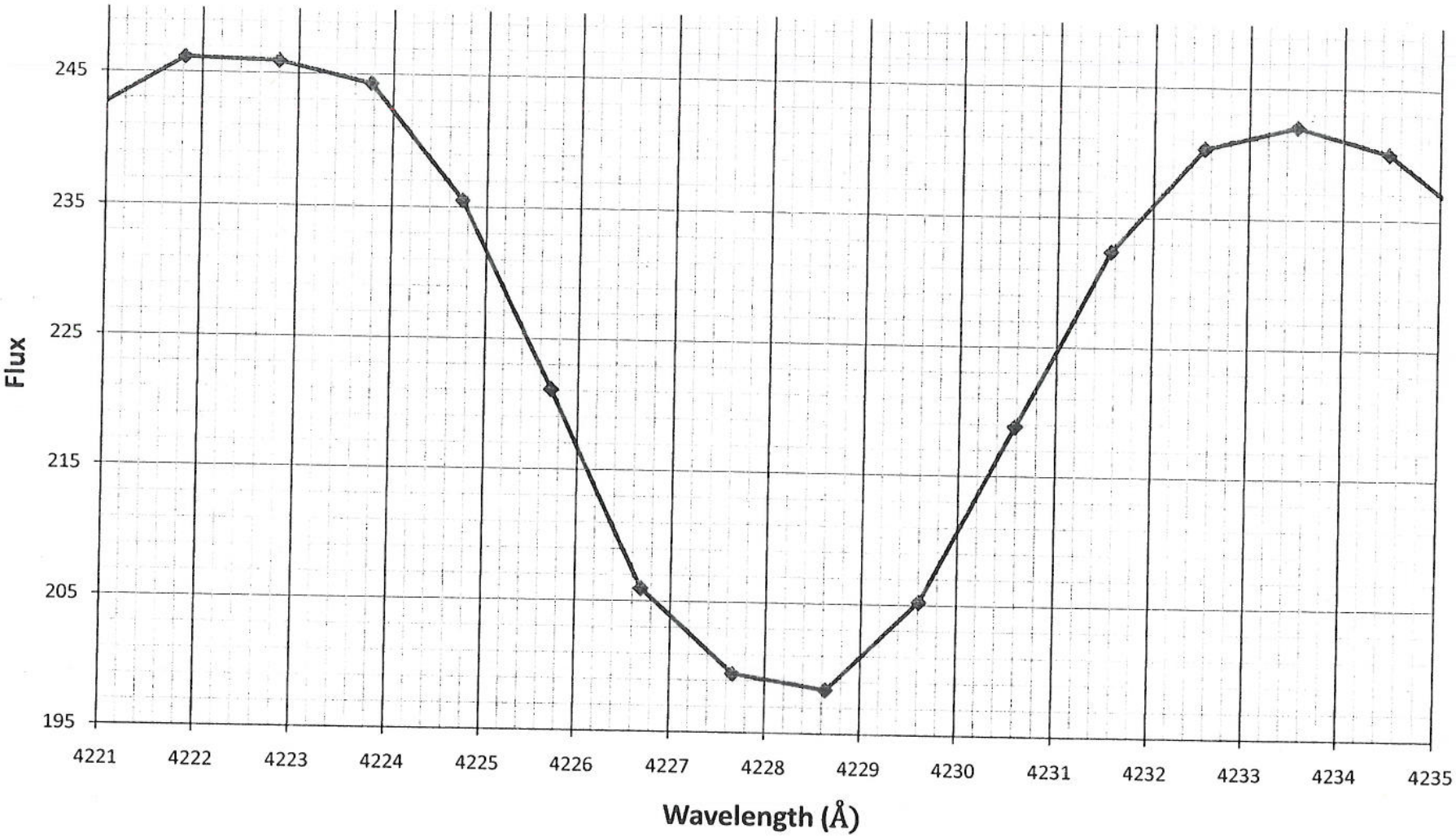
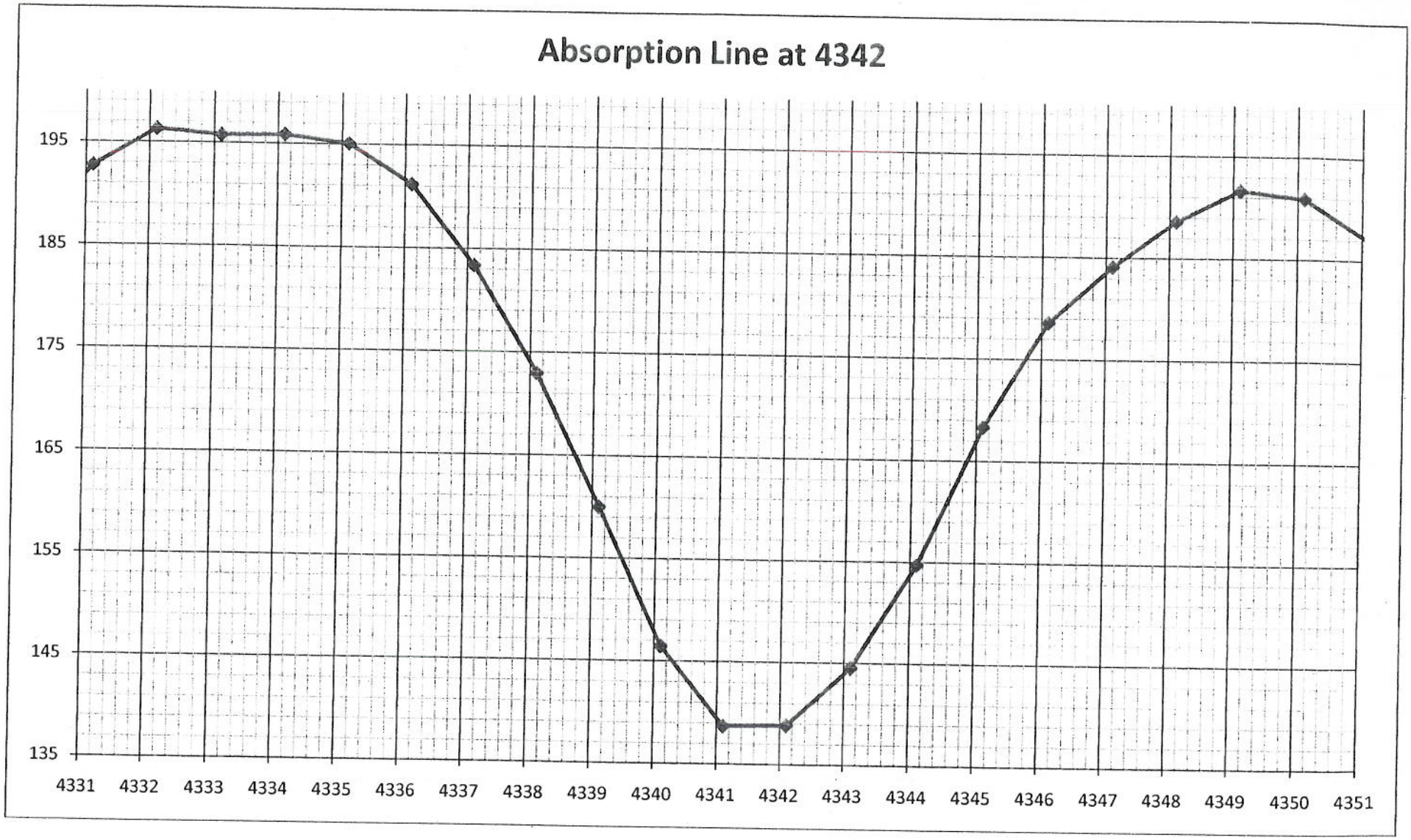
$$\sigma = \frac{FWHM}{2.35}$$

$$EW = \frac{2.5066 * \sigma * height}{continuum}$$

Star Classification	Ratio of 4226:4342
F8	0.4
G0	0.5
G2	0.65

Name: _____ Date: _____ Period: _____

Absorption Line at 4226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