

Name _____

Lab day _____ Lab Time _____

Pre-lab Questions – Complete these questions before coming to lab.

Define the following terms and answer the questions:

1. Frequency - Number of waves that pass in a given interval of time
2. Wavelength - Distance from a position on a wave to the same position of the next wave...from crest to crest, or trough to trough, for example
3. Period (in relation to waves, not geologic time!) - Length of time for one wave to pass
4. What is the speed of light in **meters** per second? -
 $3 \times 10^8 \text{ m/s}$
 $300,000,000 \text{ m/s} = 300,000 \text{ km/s}$
5. How far is Earth from Sun in miles? How far is Earth from Sun in kilometers? $93,000,000 \text{ miles}$ or $149,000,000 \text{ km}$
6. The equation for velocity is $v=d/t$ (distance over time). If you were traveling at the speed of light, how long would it take you to get from Sun to Earth in minutes? (Show your calculations, with units.)

$$\frac{149,000,000 \text{ km}}{1} \times \frac{1 \text{ second}}{300,000 \text{ km}} = 500 \text{ s} \times \frac{1 \text{ min}}{60 \text{ sec}} = 8 \frac{1}{3} \text{ min}$$

7. What conditions are necessary to produce continuous, absorption, and emission spectra? Continuous – incandescent light
Absorption – gas filtering a continuous source
Emission – gas energized until it glows

Light and Light Sources

There are billions upon billions of stars in the sky yet, due to their distance, the only star we can visit is our Sun. This distance, however, does not prohibit us from learning a considerable amount of information about these stars. Our primary source of this information is the electromagnetic (EM) spectrum, of which visible light is just a small but important slice that we can perceive with our human eyes. Also included in the EM spectrum are different frequencies that our eyes cannot perceive, such as gamma rays, x-rays, ultraviolet rays, infrared rays, microwaves, and radiowaves. Just as our human eye is sensitive to only a portion of this spectrum, our telescopes are only sensitive to particular portions of EM spectrum as well. Thus, we end up with infrared telescopes, visible light telescopes, ultraviolet telescopes, and so on.

When we investigate the universe in the EM spectrum we find that there are many different ways in which light can be produced and altered. Some examples of light that we encounter in everyday life that are produced in very different ways include sunlight, the light from incandescent bulbs, fluorescent tubes, and "neon" lights. All of these light sources produce light in different ways. Incandescent lamps emit light because of the temperature of the lamp filament, resulting in what we often call a "warm" light. Fluorescent lamps emit a "cool" light because the emission process is different from that of incandescence. The same photograph taken under incandescent light will look very different from that taken under fluorescent light because of these differences (and are often "corrected" by settings in the camera or in software afterwards). In addition, objects will also look different in sunlight due to the different frequencies of light contained in the solar spectrum.



**Incandescent Bulb
Continuous Spectrum**



**Gas Discharge Tube
Emission Spectrum**

When light from an incandescent bulb is viewed through a very fine grating or a prism, we see characteristic bands of color that we call the spectrum of the light. The spectrum we see emitted from an incandescent bulb consists of colors that blend into one another through a continuous spectrum of red-orange-yellow-green-blue-indigo and violet (ROYGBIV). This continuous spectrum has no colors missing.

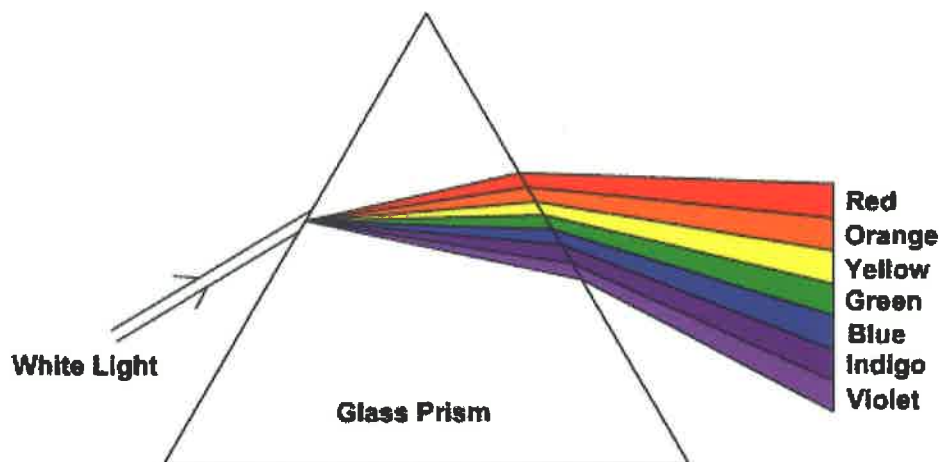


Figure 1. The continuous spectrum produced by white light such as that produced by an incandescent bulb. (Image courtesy of www.school-for-champions.com)

When we investigate the spectrum emitted by most stars, we see a nearly continuous spectrum, but one that has a series of black bands within that spectrum. Those black bands indicate sections of the continuous spectrum that are being blocked by something or many somethings. The "somethings" creating those black bands are elemental gases within the outer portions of the star. Through laboratory analyses we have found that each element blocks (or filters out) specific frequencies of light. Each element always blocks out the same light frequencies. Thus, each element has something of a unique "bar code" that it creates when filtering a continuous light source. Scientists can use this "bar code" to identify which elements are present in distant stars. This nearly continuous spectrum with missing black bands is known as an absorption spectrum (also sometimes known as a dark line spectrum).

Another way of producing light is to energize a gas at low pressure. We can do this by putting the gas in a glass cylinder and, by having electrodes at both ends; we pass high voltage electricity through it. The result is a glowing tube of gas with a specific color. True neon bulbs yield a characteristic reddish-orange glow, and are often used for advertising signs in store windows. If, however, you see other colors of glowing gas in those advertising signs, this indicates the use of a gas other than neon. If we look

at this glowing gas through a prism or grating, just as we did our other light sources, we get a very different spectrum. This emission (also known as bright line) spectrum typically consists of just a few bright lines within a predominantly black background. Just as the absorption spectrum of a particular element yields a unique "bar code" that allows us to identify it, the emission spectrum of a particular element yields a unique "bar code" of bright lines. In fact, we find that the absorption and emission spectra of a particular element are reverse images of each other. (Figure 23.3 from Tarbuck, Lutgens, and Tasa textbook).

Part A – Investigating Light Spectra

Procedure:

Go to <http://phet.colorado.edu/sims/black-body-radiation/black-body-radiation.swf> and run the simulation called "Blackbody Spectrum". (Use Internet Explorer or Firefox to launch).

This simulation has you look at graphs of Intensity vs. Wavelength for the emissions from materials at various temperatures. Virtually every object in the universe is emitting a range of wavelengths from the EM spectrum (including you and me!). In this exercise you will look at range of emissions including the Sun (very hot) to the Earth (relatively cool). As you change the temperature (using the slider or entering a number in the box) you will see the graph change. The peak of the graph is maximum intensity of emissions for that object and corresponds to a particular wavelength. Even though we may perceive visible light from an object, the color or colors we see may not necessarily correspond to the maximum EM wavelength being produced by that object. For example, we may see light from an object yet its peak electromagnetic emissions may be in the UV or IR wavelengths.

Note: You may need to use the + & - controls to get the intensity graph to fit on the screen.

1. Set the temperature slider to approximately 5800K (Kelvin) which equates to the temperature of the sun.

a. Find the wavelength of the peak of the intensity curve: 0.5 μm

b. What color(s) does this correspond to? blue green

c. Sunlight usually appears yellowish to us. Does this make sense in terms of this graph? Not in terms of this graph. The gases of Earth's atmosphere are particularly good at absorbing these colors, though, and we are left with the yellower & redder components of visible light.

2. Now set the temperature slider to the level of **light bulb**. This simulates the spectrum emitted by a typical incandescent light bulb.

a. What is the temperature of the light bulb? 3045 K

b. The peak intensity corresponds to which wavelength? 0.95 μm

c. Does this peak correspond to visible light? Circle one: **YES** **NO**

d. If the peak is at wavelengths longer than visible light, then it is probably in the infrared (IR) region of the EM spectrum. If it is at wavelengths shorter than visible light, then it is in the ultra-violet (UV) region. IR radiation is typically equated with heat. How efficient is this light bulb in providing visible light? What type of energy does the light bulb primarily produce?

The bulb peaks within the infrared spectrum and produces more heat than light. This would suggest that the incandescent bulb isn't very efficient at producing visible light.

3. Set the temperature slider to Earth. Yes, Earth has its own characteristic temperature as well.

a. What is the characteristic temperature of Earth? 300 K

b. What is the associated wavelength of this temperature (peak?)

9 to 9.5 μm (you will need to **zoom out on the horizontal scale** and **zoom in on the vertical scale** to see this peak).

c. In what region of the spectrum (uv, visible, infrared) would you need to have a detector to measure the temperature of Earth?

We would need an infrared detector to see 9 micrometer or 9000 nm wavelengths

Part B – Ultraviolet Light and Fluorescence

Fluorescence is a term we encounter every day; in things like fluorescent lights, fluorescent highlighting pens, etc.; but what is it? This section will allow us to look at how fluorescence is created, some examples of fluorescence, and ways in which fluorescence is used. Though fluorescence can occur with a variety of wavelengths, one common and useful example is when ultraviolet radiation (which is out of the range of visible human perception) is shifted into slightly longer wavelengths and yields visible light.

Webster's dictionary defines fluorescence as "the emission of radiation, especially of visible light, by a substance during exposure to external radiation, as light or x-rays." The key concept here is that some form of EM radiation of one wavelength interacts with a material which then re-emits that radiation at a different wavelength. The re-emitted wavelength is often slightly longer in wavelength than the original source, though there are a few exceptions to this generalization. Fluorescence is different from reflection, in which a material bounces back the same wavelength it has received.

We most frequently hear the term "fluorescent" in reference to the lights that we use in the office and home. So what is fluorescent about them? Strange as it may seem, the EM radiation in a fluorescent tube does not start as visible light. By passing high voltage electricity through the tube, mercury vapor is energized until it emits EM radiation. The EM radiation thus produced is primarily within the ultraviolet spectrum and cannot be perceived by the human eye. Invisible UV radiation would not be very helpful for helping illuminate our homes, so something needs to happen in order to produce visible light! The key is the phosphor coating bonded to the glass of the fluorescent tube. Every fluorescent tube you have ever observed has some sort of white-ish coating on the glass. That coating interacts with the UV light and, through fluorescence, shifts the wavelength into the visible spectrum. This produces the light that we can use.

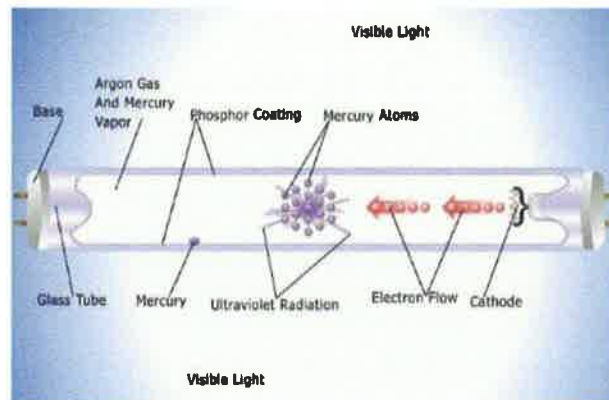


Figure 2. Schematic of a typical fluorescent tube.

One of the first examples of fluorescence observed by scientists was by the mineral fluorite which, as you might expect, glows when exposed to under UV radiation. The term “fluorescence” was named after this property of fluorite. Many other minerals display this quality as well. In addition, many organic materials also exhibit fluorescence. Those of you who watch detective shows on television may be familiar with investigators using UV lights at the scene of a crime to help detect various bodily fluids. Biologists and enthusiasts of scorpions also use UV lights to detect them at night (most scorpions are nocturnal hunters). Because of the composition of their bodies, scorpions exhibit a characteristic blue-green glow when observed under UV light.



Figure 3. A scorpion under visible light (top) and under ultraviolet light (bottom). The blue-green glow of scorpions under a “black” light is a result of fluorescent compounds shifting the wavelength into the visible spectrum.

Activity 1: Ultraviolet light

A so-called 'black light' is actually an ultraviolet light source. By ultraviolet, we mean light of a wavelength just shorter than the visible part of the spectrum.

1. Why does the poster glow with green light when it is illuminated with **invisible light**? The pigments of the poster absorb the ultraviolet light, and this causes electrons to increase in energy level. When the electrons go back to stable level, they re-emit the energy at visible-light frequencies that we see as a fluorescent glow.

You may have also noticed that your clothing, particularly white clothing, glows when illuminated by a black light (an ultraviolet light source). This is because detergent manufacturers put fluorescent chemicals in laundry detergents. To demonstrate this fact, shine the black light on the sample of laundry detergent.

2. Why does including fluorescent chemicals in detergent make your clothes look 'whiter and brighter'?

The fluorescent compounds in the laundry detergent leave remnants in clothes after washing. Sunlight contains ultraviolet wavelengths, and the detergent does fluoresce in sunlight. The visible light outshines the fluorescent glow, but the fluorescence enhances the 'brightness' of the clothing. It is a marketing trick by detergent manufacturers.

3. Every summer we hear news reports that wearing a t-shirt does not provide very good protection from getting a sunburn. In fact, a new t-shirt directly off the store shelf only has a sun protect factor (SPF) of about 6 (which means you can stay out 6 times longer in the sun before burning than if you were not wearing the t-shirt). This probably conflicts with our own experiences, however, as most of us never even get a hint of a tan under our t-shirts, much less a sun burn. What those news reporters fail to tell their readers/listeners is that washing your t-shirt in standard laundry detergent 5-6 times will result in your t-shirt being approximately SPF 60. Why does washing your shirt increase its SPF factor? The same fluorescent compounds that cause our clothes to look brighter also act as a filter to the UV light. They reduce the amount of UV radiation that reaches our skin.

Part C – White Light and the Visible Light Spectrum

Light from the stars and planets can contain a wealth of information about the object it came from. It is not so easy to look at starlight, so we will have to be creative. This station consists of several light sources and a set of spectrosopes. A spectroscope splits light into its visible component wavelengths and measures the wavelength of the light waves. Your job is to measure the wavelengths present in each light source.

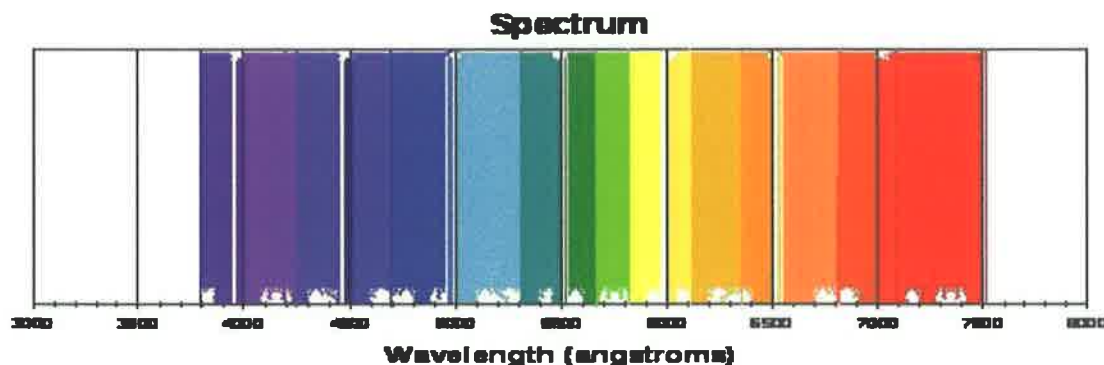
Activity 1: ROYGBIV Spectrum of incandescent tungsten lamp.

The **first source** is an incandescent tungsten filament lamp. With your instructor's help, use the spectroscope to view this source. You should see a *full spectrum* or range of visible wavelengths. Be sure to note that units in the spectroscopes are nanometers, and the wall charts are in angstroms. You will have to convert to compare these.

Make observations of the incandescent filament lamp with the spectroscope. Record the **range of wavelengths** that comprise each color of light, in nanometers (billionths of meters). Red is done for you.

R ed light	from	<u>750</u>	to	<u>640</u>	nanometers
O range light	from	<u>640</u>	to	<u>590</u>	nanometers
Y ellow light	from	<u>590</u>	to	<u>560</u>	nanometers
G reen light	from	<u>560</u>	to	<u>500</u>	nanometers
B lue light	from	<u>500</u>	to	<u>440</u>	nanometers
V iolet light	from	<u>440</u>	to	<u>380</u>	nanometers

On the graph below, mark (in color) the appropriate ROYGBV wavelengths.



Activity 2: Star Composition

Astronomers learn a vast amount of information about a star from analyzing the electromagnetic spectrum that emits from it. Comparing a star's spectrum to the spectrum of known gases (as viewed on Earth in a laboratory) allows scientists to theorize about the star's compositional makeup. A star whose spectrum closely matches that of a hydrogen-filled discharge lamp (as viewed in a lab) is, with a high degree of confidence, assumed to be composed of Hydrogen gas. In this activity you will be given two unknown "stars" (actually they are gas-filled discharge lamps), and you will have to compare their spectrum with known spectra and deduce the star's composition.

PLEASE READ THE WARNING BELOW.

WARNING:

KEEP CLEAR OF THE LAMP WHEN IT IS OPERATING.

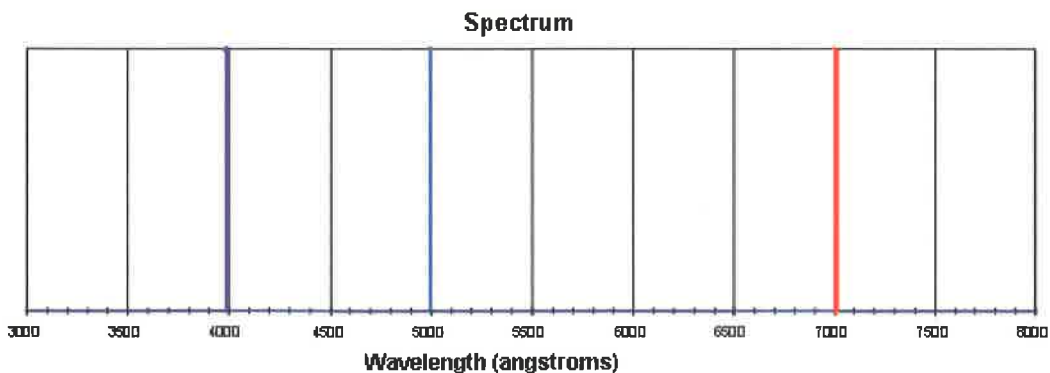
THE HIGH WATTAGE IS DANGEROUS.

TURN THESE LAMPS OFF UNLESS YOU ARE ACTUALLY USING THEM.

THE LAMPS HAVE A LIMITED LIFE. LEAVING DISCHARGE LAMPS when you are not using them MAY RESULT IN **DEDUCTION OF POINTS** ON YOUR LAB!

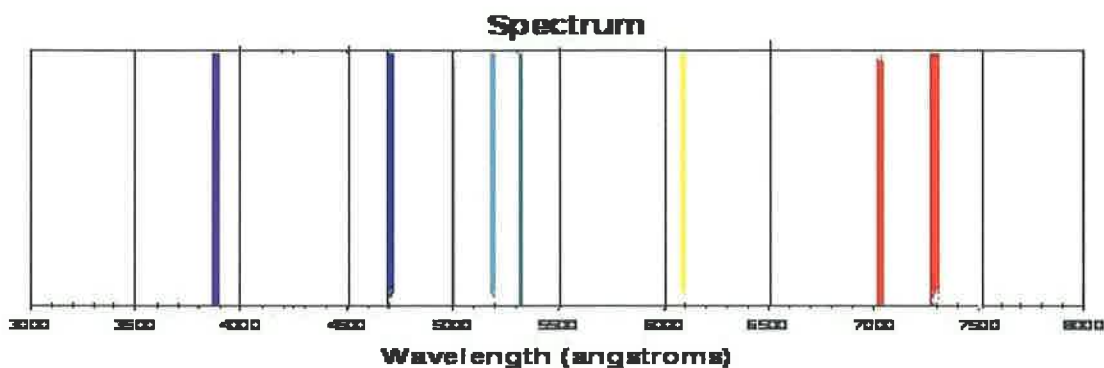
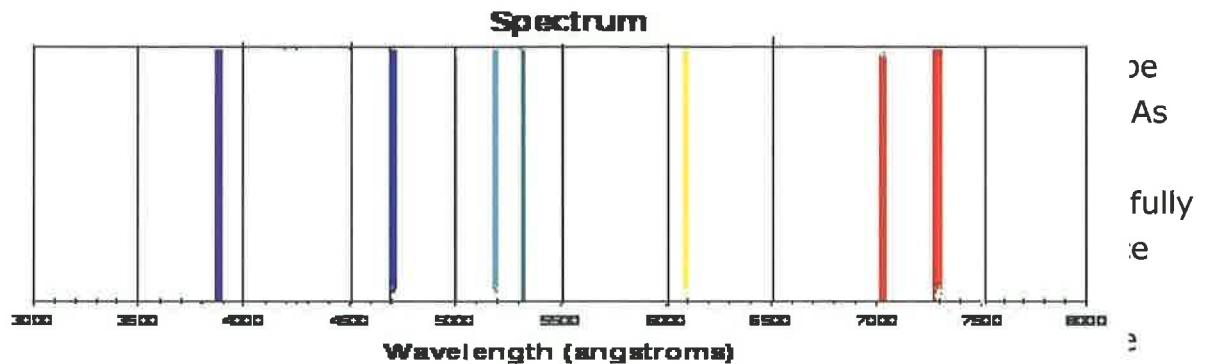
Alpha Star

Turn on the discharge tube for **Alpha Star** (you are using the discharge tube as a model of an unknown star comprised of a **single** gaseous element). Make observations of the colors and placement of **Alpha Star's** spectrum. Record your observations on the graph below. Be sure to carefully observe the number (wavelength) under the colored spectral line and place your "colored" line in the corresponding place on the graph.



After drawing the spectrum of Alpha Star, compare it to the chart of spectra from known gases on the classroom wall. **What gas do you think Alpha Star is predominately made of?** If there is more than one possibility, list them all. Explain your reasoning. How confident are you?

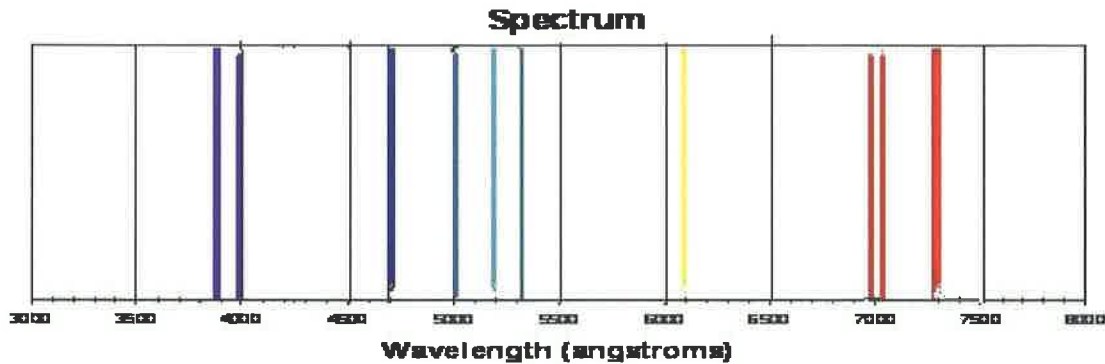
Helium



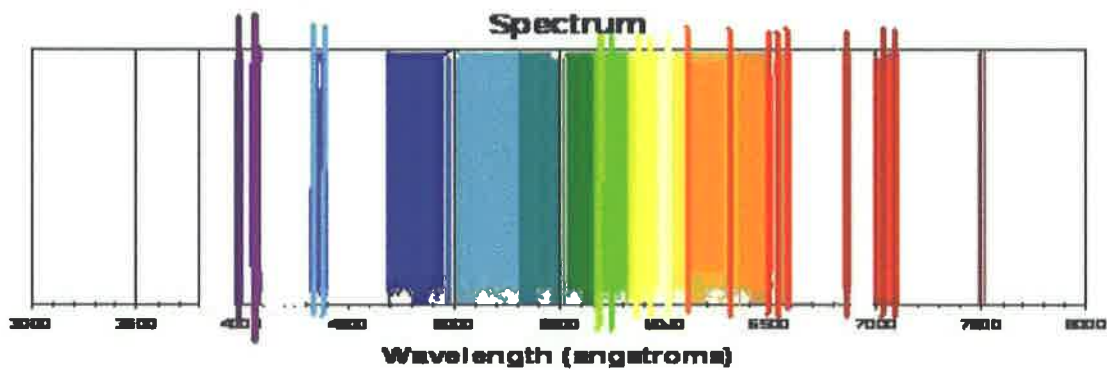
After drawing the spectrum of Beta Star, compare it to the chart of spectra from known gases. **What gas do you think Beta Star is predominately made of?** If there is more than one possibility list them all. Explain your reasoning. How confident are you?

Hydrogen

On the graph below, draw the spectrum of a third star, which is composed of a mixture of the gases of Alpha Star and Beta Star.



Fluorescent Star: Observe the fluorescent lamp through the spectroscope. Carefully record Fluorescent Star's spectrum on the graph below and compare it to the chart of known gases.



What gas do you think is inside a fluorescent tube lamp? (Perhaps it is a mixture, where Alpha Star and Beta Star were each only one gas. If you think so, list more than one element, and explain why you think this.)

Mercury & Potassium

Activity 3:

Compare two light sources of the same wattage: The wattage of the lamp tells you how much electrical power the lamp is consuming. Visually compare the brightness of the incandescent and fluorescent lamps. Why does the fluorescent lamp appear brighter than the lamp with the incandescent bulb?

Consider the glowing material and its physical state (*Hint: Hold your hand next to each lamp.*) The incandescent lamp turns some electricity into heat. The fluorescent lamp is more efficient, and uses less electricity for heat, and more for light, so it can produce the same brightness with less electricity.

Questions:

1. Did the different gases in the discharge tubes (**Alpha and Beta Stars**) produce the same spectrum or a 'signature' spectrum different from each other? Different

A *continuous spectrum* is one in which all wavelengths are represented (an uninterrupted band of colors). A *discrete spectrum* does not have **all** wavelengths represented; some wavelengths are missing. Your textbook described two types of discrete spectra: *bright line emission spectrum* (like the discharge tubes create) and *dark line absorption spectrum*. Look at the spectrum of the Sun on the poster from which you obtained the known spectrums of gases. Notice that the solar spectrum is missing discrete wavelengths (these are represented by black bands); it is a dark line absorption spectrum.

2. What relationship do you notice between the missing wavelengths from the solar spectrum and the emission spectrums of the gases on the chart ? Dark lines exist where emission spectrum bright lines are for the same gas.
3. What does this tell you about the wavelengths at which each gas emits and absorbs light? A gas emits and absorbs at the same wavelength
4. Based on the solar absorption spectrum, identify at least two gases present on the Sun. Sodium, hydrogen, calcium

Name _____

Lab day _____ Lab Time _____

POST LAB ASSESSMENT

1. Members of the military are instructed to not use laundry detergent that has "brighteners" in it. Why would they be given these instructions? (consider our investigations of laundry detergent in this lab).

If their clothes had fluorescent compounds in them, enemy combatants could use an ultraviolet light source to make them glow. The soldiers would light up like a scorpion under this light source and be easy targets.

2. What sorts of information do astronomers have available to them from the stars? In what form does it come?

Light and position.

Light:

- Spectrum gives the gases that the star has for composition.
- The shift of the spectrum would indicate at what speed the star and Earth are receding from or approaching one another. There will be a shift toward the red end of the spectrum in receding objects, and a shift toward the blue end of the spectrum for approaching objects. The light does not become red or blue, just shifted along the scale toward one end or the other.
- Temperature—hotter stars are bluer, cooler stars are redder.

Position: The parallax angle, the shift in position against a backdrop of far-away stars, can be used to calculate distances.

3. Suppose that someone gave you a sample of an unknown gas. How might you go about identifying it *using techniques learned in today's lab*? (outline a procedure with detailed steps)

You could heat the gas to glowing, and observe the spectrum emitted. This can be compared to known spectra of gases, and each has a unique signature spectrum. The gas can be identified by this technique.