Name:___________________________

Lab #01
Properties of Light
Jan. 31, 2018
Remote Sensing 4113

Equipment needed: Calculator, plus provided tools such as LED's spectrometer, etc.

The purpose of this lab is to explore the wavelength properties of light using a simple spectrometer and light sources such as LED's, a laser, a fluorescent lamp, and an incandescent lamp, then to explore the properties of human color vision using addition light sources and filters.

See the spectrometer instructions at the end for how to position the light sources relative to it, how to look through it, see the spectrum, and read the wavelengths of the light..

You will be provided with 5 LED's numbered 1-5, a current source to run them, and a simple spectrometer. You can cause the LED's to glow by plugging them into the sockets. The longer pin of the LED should go into any hole in the upper row, marked with the "+" sign, while the shorter pin should go into any hole in the lower row, marked with the "-" sign. (The LED label is on the longer, "+" pin.) You won't damage them putting them in backwards, but they won't illuminate in that orientation. **(Do NOT connect the LED's directly to the battery -- that will burn them out.)**

1. One after another, plug the LED's #1 - #5 into the sockets, and fill in the color of the emitted light in the table below. Next, one after another, look at the LED's through the spectrometer. List the range of wavelengths that are present from each of the 5 LED's. Don't try to judge the very shortest and longest wavelength you see as that will be very dependent upon variables such as the exact brightness of the LED and whether you are dark adapted. Instead, try to estimate when the wavelengths where the brightness of the spectrum as faded to roughly ½ of its maximum value. This will still be somewhat viewer depended. Try to look "straight down" on the LED, i.e. along its axis, as that makes it appear brightest.

#	Color	Min. λ	Max λ
1	__________	_________ nm	_________ nm
2	__________	_________ nm	_________ nm
3	__________	_________ nm	_________ nm
4	__________	_________ nm	_________ nm
5	__________	_________ nm	_________ nm

2. Which three "primary color" LED's have wavelength ranges which are separate, in that they more-or-less do not overlap each other in wavelength, and produce more-or-less a single color as seen in the spectrometer? Note that all of the LED's do have "wings" which extend into neighbor colors. Ignore those and consider just the region of high brightness.

1. ________________ 2. ________________ 3. ________________

3. Which two LED's have bright emission wavelength ranges which clearly overlap those of the three "primary" ones, producing clearly different colors in the spectrometer? (Again, ignore the fainter "wings".) If you wanted to produce that range of wavelengths by combining the "primary color" LED's, which ones would you need?

1. ________________ Primaries needed: ___________________
2. ________________ Primaries needed: ___________________

4. Examine the spectrum produced by the laser pointer. DO NOT LOOK DIRECTLY AT THE LASER POINTER. DO NOT SHINE IT DIRECTLY INTO THE SPECTROMETER TOWARDS YOUR EYE. Place a thin piece of paper over the spectrometer entrance hole and shine the laser on that. Some laser light will make it into the spectrometer.

What is the center wavelength of light output by the laser? Does it cover an extended wavelength range like the LED's or does it produce a very narrow wavelength range? If the laser emits a narrow-enough range then the broader range you do see with the spectrometer is an artifact due to the spectrometer and represents the instrumental spectral resolution – the spectral equivalent of spatial resolution. Try to estimate that range, or at least produce an upper limit to its width (i.e. it is narrower than ??? nm).

1. Central wavelength ____________ and description:

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2. Spectrometer resolution (or at least upper limit to width) ________________

   By resolution, we mean, how close in wavelength to the existing laser spectral line could we place a second laser and you would be able to tell there were two separate laser lines present, rather than a single merged line. A very good spectrometer would let you distinguish two lasers very close in wavelength while a cheap spectrometer (like this) would only let you the two lasers if their wavelengths were farther apart.

5. Look at the fluorescent lights with the spectrometer. This type of light bulb consist of an electrically excited gas (part is mercury) which glows at discrete wavelengths, many in the ultraviolet but some in the visible. The inside of the tube is coated with a phosphor which converts the UV light to a continuous spectrum of visible light. However some of the "line emission" from the gas escapes and will be visible with the spectrometer. Record the wavelength of the three most prominent emissions lines.

1. __________ 2. _______________ 3. _______________

6. An incandescent bulb, unlike a fluorescent one, glows because it has a hot filament. In this experiment the bulb is plugged into a dimmer which can reduce the current flowing through the bulb therefore vary the temperature of the filament.

1. Turn on the bulb turn up the dial to maximum, then look at the bulb through the spectrometer. Record the range of wavelengths which are visible. Try to estimate the wavelength of peak "apparent" emission.

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(Note I've added the word "apparent" in the question above because your eye is not a well calibrated intensity measuring device. The real peak will be at longer wavelength than you estimate, but your eye is just less sensitive to those. Its peak sensitivity is in the green.)

2. Gradually turn down the dial till the bulb is just barely glowing. Describe any change in the color of the bulb as observed directly by eye. Then look through the spectrometer and describe how the spectrum has changed.

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Human color vision

As described in Chapter 1 and 2 of our text, humans can sense colors because we have three different kinds of color receptors or "cones" in the retina of our eye (in addition to the rods which are sensitive to a broad wavelength range for dim-light "monochrome" vision. One set of rods is sensitive to blue light, one to green, and one to red. In some sense our eye (and brain) tries to estimate the "wavelength" of the incoming light by monitoring which of the three sets of rods respond. Obviously blue light makes the blue sensors respond, green makes the green ones respond, and red makes the red ones respond.

Because their sensitivity range partially overlaps a yellow wavelength intermediate between red and green makes both those sensors respond. A cyan wavelength intermediate between green and blue makes both those sensors respond. We can "fool" the brain into seeing yellow by simultaneously shining both red wavelengths and green wavelengths into it, even when no yellow wavelengths are present. Similarly we can "fool" the brain into seeing cyan by simultaneously shining both green and blue wavelengths into it.

In reality the eye and the (uneducated) brain don't know anything about wavelengths – just how much the R,G,B cones are responding. For example the brain interprets a response from the R and B sensors, but not the G sensors, as the color magenta. However that isn't a color which exists in the spectrum – a wavelength half way in between red and blue would actually be green.

A "perfect" photograph would reproduce exactly the same spectrum of light from every point which fell on the camera – but that is a technically impossible request. Instead, color cameras simply have sensors which match the same red, green, and blue response as they eye, then reproduce the right amounts of red, green, and blue in the image. That is all the eye cares about – but the detailed spectrum of the incoming land the reproduced light could be very different.

Red, Green, and Blue are called primary additive colors because the eye can be "fooled" in seeing any color by combining the right amounts of these.

7. The instructor will display on a computer monitor overlapping circles of red, green, and blue light on the screen. Fill in the figure below showing what colors you see in the three main circles, in the 3 sections where just two colors overlap, and in the very center where all three primary colors overlap.

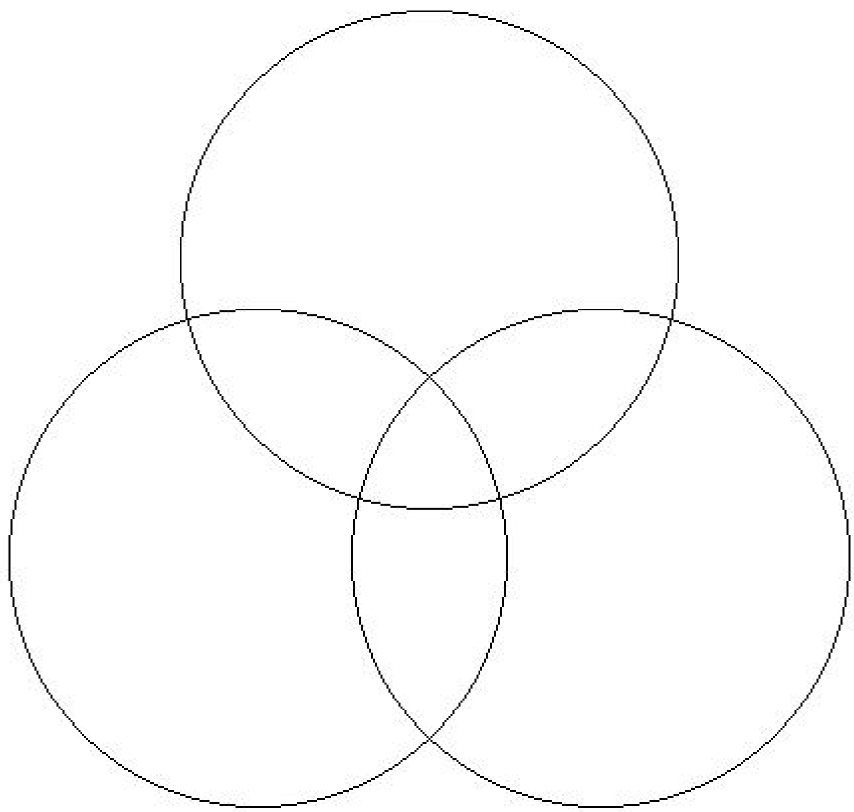
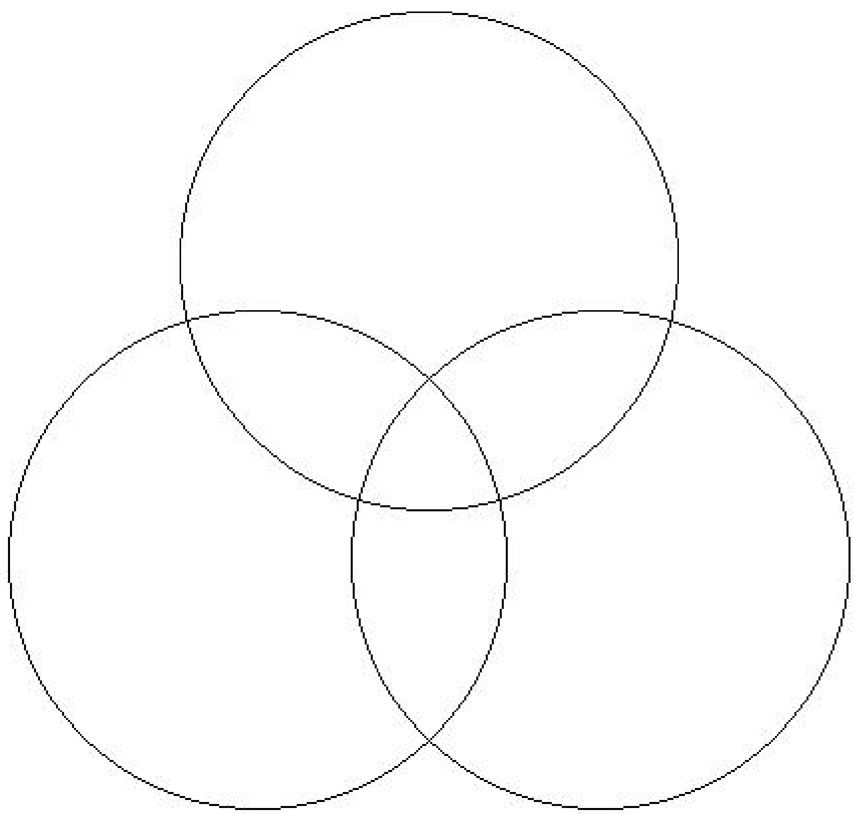


Figure 1.

8. Next, look at the monitor with a hand lens (i.e. magnifying class). You should see phosphors made up of just three colors, with different ones illuminated in different sections of the diagram. When you don't have the magnifying class your eye blurs the different phosphors together, in effect adding the light from the different phosphors. In each of the seven sections of the diagram shown below, list which phosphors are illuminated.

Figure 2.



Subtractive colors

The primary colors discussed above are "additive" primaries, in that you obtain new colors by adding light of different primaries. However in printing and in film you must start with white light and "subtract" unwanted colors. If you could create small enough dots which didn't overlap you could in theory use additive colors but in practice the ink deposited on a page (or the dyes in film) will overlap. The only wavelengths which survive will be those which can pass through ALL of the inks or dyes which are present. We still need three primaries, but the SUBTRACTIVE primary colors will be those formed by the combination of two additives at a time: YELLOW (=red + green), CYAN (=green + blue), and MAGENTA (=red + blue). Since the yellow ink in a printer passes both red plus green wavelengths, and the cyan passes both green plus red, if we deposit both on a page only green light will pass through both and be reflected. Red and blue will be blocked by one or the other.

9. To verify the above explanation, you will be given three filters – yellow, cyan, and magenta. Look through the spectrometer and then the filter at a white light source. (The WHITE LED works best.) List the range of wavelengths which are transmitted. Note that with two of the three color filters the transmitted light will cover one continuous wavelength range, but with a third filter there will be two discrete separated wavelength ranges, and one if those ranges may be much fainter than the other.

YELLOW: ____________________________ nm

CYAN: ____________________________ nm

MAGENTA: ____________________________ nm

10. Repeat the above experiment, but look through two filters at a time. Record the range of wavelengths seen through the spectrometer, and the apparent color of the transmitted light as seen by your eye.

	Wavelength range	Color
YELLOW + CYAN:	____________________________ nm	____________
CYAN + MAGENTA:	____________________________ nm	____________
MAGENTA + YELLOW:	____________________________ nm	____________

Quantitative estimates of emitted power and wavelength.

As we'll see in more detail in Chapter 5, we can quantify the nature of the incandescent spectrum we saw in part 7 as we raised and lowered the temperature of the incandescent filament. The power per unit area (the "flux") from an ideal hot surface (a so-called "blackbody") is given by the Stefan-Boltzmann law, equation 5-5

$$F = \sigma T^4$$

where T is the temperature measured in Kelvin (so this is the "absolute" temperature), and σ is the Stefan-Boltzmann constant, 5.67×10^{-12} W cm^{-2} K^{-4}. For example a surface at 1000 K would emit 5.67 W from each square cm. Because F depends on the fourth power of temperature, the flux will go up by a factor of 16 each time the temperature is doubled.

As we saw, the wavelength of the most intense emission shifts to shorter wavelength as the temperature is raised. That wavelength is given Wien's displacement law, equation 5-1:

$$\lambda_{max} = (2897\ \mu m\ K) / T$$

For example a surface as a temperature of 100 K will radiate most intensity at a wavelength of 28.97 µm, or 28,970 nm. The following Figure 5.2 from our text shows the emission from blackbodies of temperatures 300 to 700 K.

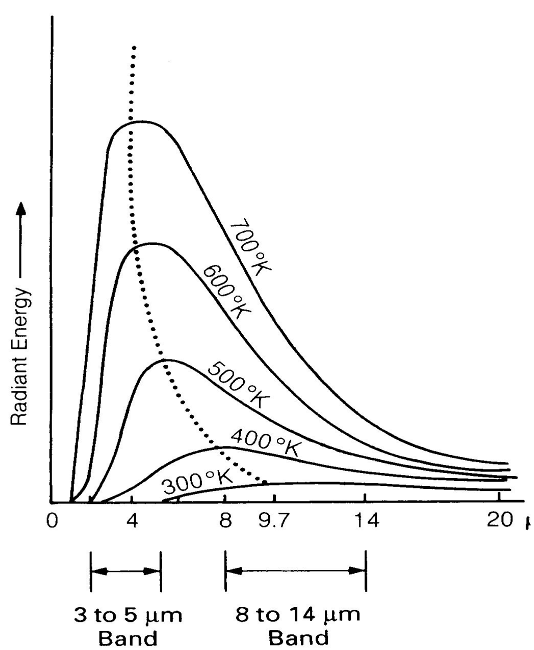


Figure 3. The blackbody emission as a function of temperature.

11. A typical room temperature is 300 K. **CALCULATE** the wavelength of peak emission from a blackbody at this temperature, and compare this to the above figure to check your answer.

12. Use your estimate of the incandescent bulb's peak intensity wavelength from question 6-1, in combination with Wien's law, to estimate the temperature of the filament. (Note the temperature you get will be really be slightly too high, because as mentioned in 6-1 your eye will see an "apparent" peak intensity wavelength which is too short.

13. Suppose that for a typical 100W light bulb 1% of the power goes into radiated light and the rest is wasted in generating heat. Use this power and the above questions to estimate the required surface area of the filament. (The real filament area will be larger, since it's actual temperature will be lower.)

14. Suppose a typical person has a temperature of roughly 300 K, and has a surface area of 1 square meter. (You will need to convert this to cm^2.) How many watts of power is radiated by that person? Note this won't be the NET power lost unless the person is out in space, because on Earth the surrounding environment will be radiating almost this much power back at the person.

Spectrometer Instructions

The light to be analyzed by the spectrometer enters through the small slit at one end of the wide end of the “triangle”. It is recessed inside the square opening. While looking through the opening at the narrow end of the triangle, point the slit at the source your are interested in viewing. The other part of the wide end contains a plastic film with a wavelength scale printed on it. That scale should be illuminated by moderate ambient light.

To view the spectrum look in the opening near the “point” of the triangle, towards the back lit scale. The light coming in the slit will be bent by various amounts (depending on wavelength) as it passes through the spectrometer, and you can measure its wavelength against the back lit scale. The wavelengths are listed in nanometers, running from 400 to 700 nm. For now ignore the other scale running from 1.7 to 3.4.

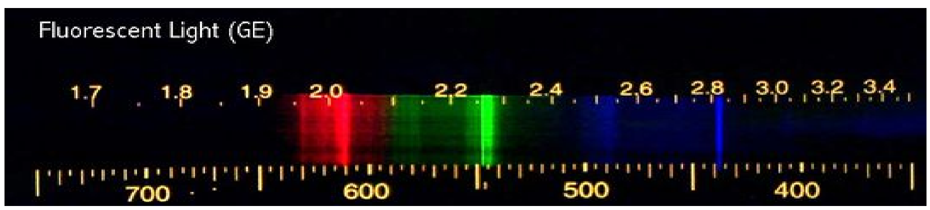


Figure 4. The view through the spectrometer, looking at some types of fluorescent lights, from Rob Brown's web site.

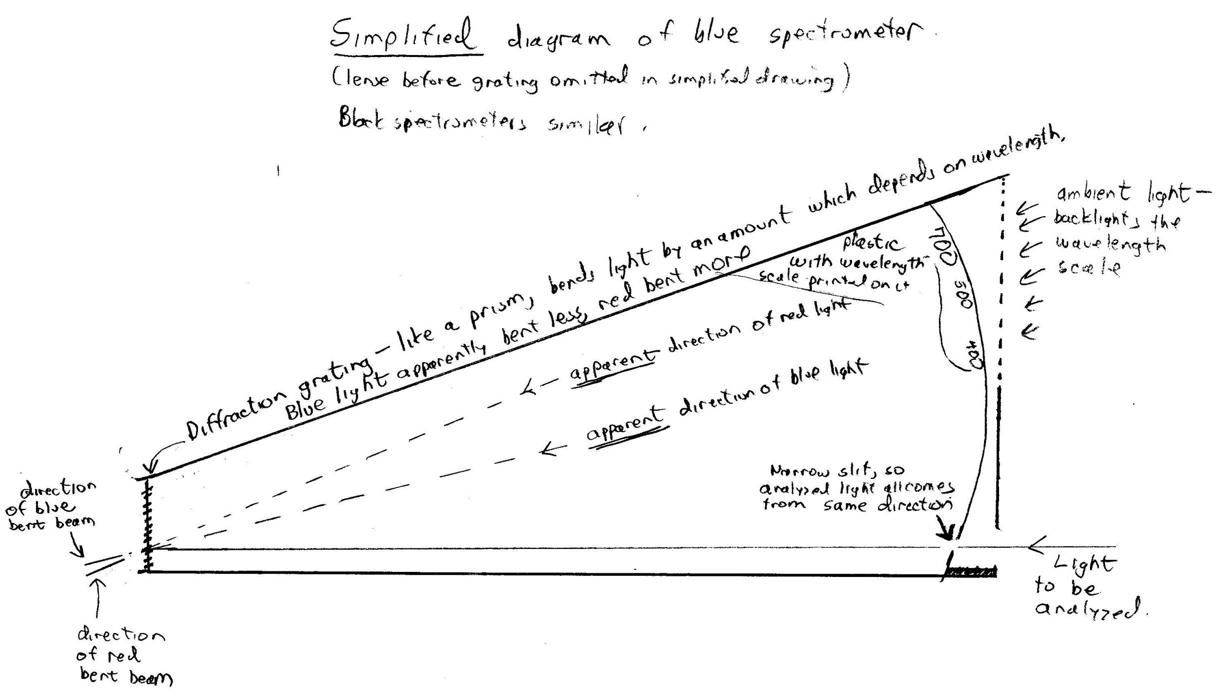


Figure 5. A simplified sketch showing the operation of the spectrometer.