UCF

COLLEGE OF ENGINEERING
AND COMPUTER SCIENCE

Absorption Dependent Intensity Detector for Chlorophyll

EEL 4914 / OSE 4951 : Senior Design 2
Dr. Samuel Richie, Lei Wei, Aravindar Kar

Senior Design Group #7

James Aurilio, Photonics Engineering (PSE)
James Brutus, Photonics Engineering (PSE)
Logan Farley, Electrical Engineering (EEL)

Table of Contents

1 - Project Outline

To begin, we have outlined the general motivation, goals, and scope of our final senior design project. This section will cover the foundational issue upon which our design can be practically applied towards solving. Any context or background information needed for the reader to understand the purpose of the intended end product will also be covered for the reader's situational awareness.

1.1 - Project Narrative Description

For our senior design project, we've built a device that exploits the wavelength dependent absorption properties of chlorophyll to detect its presence and relative concentrations in aqueous solutions. To begin, we'll cover some of the motivations behind our design. Fresh water in Florida, for example, varies over time in its phytoplankton concentrations. As phytoplankton in water increases, the water appears more green, indicating higher levels of chlorophyll content. The chlorophyll impurities can be sparse, sometimes being measured at just a few parts per million in concentration. The chlorophyll content of fresh water lakes, rivers, swamps in our ecosystems are great indicators of environmental stability and can provide insight into phytoplankton populations which serve as the fundamental basis of countless biological energy cycles.

We have designed an Absorption Dependent Intensity Detector for Chlorophyll. The purpose of our design is to identify concentrations of chlorophyll impurities in fresh water samples. Our device is a commercially affordable device that focuses on the ability to detect just chlorophyll impurities. Our device puts the capability of detecting chlorophyll concentrations in the hands of retail buyers. It is designed to be a table-top, plug-in device and it is expected to be as user-friendly as most common household appliances. The user will be able to scan for chlorophyll compounds in their respective environment's water sources. The device informs the user of the amount of chlorophyll in the provided water sample being scanned.

Current spectrophotometer devices, which our initial designs were intended to replicate, are generalized to detect a wide range of chemicals and compounds, requiring extremely sensitive designs to accomplish. This makes most spectrophotometers relatively expensive, ranging from $10,000-15,000, which defaults such tests to third-party companies to administer. Spectrophotometers utilize a range of select wavelengths that allow them to detect the presence of certain chemicals, compounds, or elements dissolved in aqueous solutions that we will refer to as impurities. Spectrophotometers exploit the absorption and transmission profiles of such impurities to show a distinct difference in the intensity of the incident light versus the received light, after passing through a sample containing the impurity.

Initially, we intended to build a device that utilizes spectrophotometry concepts to detect non-organic impurities found in tap water systems. We selected this avenue since tap water in Florida is notorious for hosting a variety of impurities that can be considered harmful to its consumers. These impurities can be sparse, ranging from just a few parts per million in concentration, however, these levels can lead to the development of chronic health issues (such as cancer, liver/kidney disease, and reproductive difficulties) over a duration of time. Elements such as lead, mercury, aluminum, and copper resemble few of countless examples of impurities that can be present in modern housing tap water systems that can be responsible for these health developments.

To detect these types of impurities, we planned to use a matter investigation technique called spectroscopy which is often used to identify these impurities. Spectroscopy is a branch of science concerned with the measurement of light produced when specific molecules/elements react with electromagnetic radiation. Each element has a 'signature' spectral profile that is unique to itself. Elements can only absorb or emit photons at discrete well defined values. When illuminated with a specific wavelength of light that falls within an element's absorption spectrum, electrons in this element will be excited and will become elevated energy levels. When these electrons return to their original level, the atom releases energy in the form of a photon at defined wavelengths which produces a unique spectral profile that we can use to identify it. For example, when hydrogen gas is excited, it emits light in the visible spectrum at 410, 434, 486, and 656nm. These wavelengths also define hydrogen's absorption spectral profile. No other element emits at this specific set of wavelengths.

There exists several types of technologies that specialize in the identification of specific elements through spectral analysis. Devices such as mass spectrometers are used in industry to perform water quality tests by government/corporate water management organizations to ensure that impurities remain at levels safe for human consumption. Occasionally, these tests may come back negative at a test site, whereas at an exit location (i.e. your household faucet) impurities can be added to a your water source due to corrosion and/or damage to a household piping system. Impurities occur due to the wide usage of plastics in storing water for commercial use, as well. Our senior design project will be to develop a device that can test for specific water impurities in a household by exploiting spectral analysis techniques, which are briefly explained above.

We developed a system that engages this concept, albeit only utilizing select wavelengths from narrowband LED sources, to detect chlorophyll impurities present in a water sample. The primary physical property that will be used to determine the presence and quantities of chlorophyll impurities will be the Lambert-Beer Law, which highlights the ability to calculate the concentration of a substance when both input and output intensities are known in adjunction with the chemical absorption coefficient. The design's ability to detect chlorophyll concentrations will allow users to detect the amount of photosynthetic material present in just about any organic material. Indicators of photosynthetic capabilities can be used to better understand organic materials and their macroscale impact on surrounding environments.

1.2 - Project Goals and Objectives

The initial goal was to allow the user to pick the trace element for the device to scan for or allow the user to pick a general option that will show all the trace elements present in the water to showcase for the user. It was also intended to alert the user if the amount of trace elements in the water were unsafe based on these readings.The current and ending goal of our design, however, is to identify chlorophyll in provided water samples from natural environmental sources. The design resembles a commercially affordable table-top, plug-in device that is moderate in size (comparable to a shoebox) and as user-friendly as most common household appliances. The user can read a live transmission dependent voltage response from the device that corresponds with the concentration of chlorophyll content in a provided water sample.

The device allows the user to test their own water,which can be inserted into the device via a detachable glass vial. Water from environmental sources, or their sink, for example, can be fed into the device to scan for the presence of chlorophyll. The device displays the resulting voltage response indicating levels of chlorophyll in the water sample provided by the user.

1.3 - Project Function

The product, as stated above, measures the level of trace chlorophyll particles present in a water sample provided by the user to determine relative concentration levels. A vial containing 150.8ml of distilled water will need to be provided prior to each test to normalize the system as a control reference. The user will then need to provide 150.8ml of water, with the impurities present as a follow-up test sample, to be scanned by the device. During each test, ambient light levels will need to be kept consistent. It is recommended to operate the device under oblique encasings to eliminate the influence of ambient light entirely. The device will then display detected voltage levels with respect to the control reading for the user.

The powered on device illuminates the provided water sample under predetermined optical conditions and intensities. Depending on the concentrations of chlorophyll impurities in the water sample, there will be an expected change in light intensity being transmitted through the sample. The expected changes will be provided based off of research on chlorophyll wavelength dependent absoprtion properties that can be found throughout a variety of online resources. Chlorophyll absorption properties is a widely studied topic and the resources available were utilized to optimize this device. Three wavelength groups, which are elaborated on further in this document, will be utilized for chlorophyll detection in aqueous solution. The three wavelength groups were selected based off of the research done to conceptualize this device. Based on the parameters set during control sample tests, accommodations were made in the device to account for wavelength responsivity variations in the measuring device, wavelength emmittance intensity from the selected LEDs, and any loss due to optical devices in-between that effect light intensity. Again, the purpose is to highlight the changes due solely by the introduction of chlorophyll in a water sample.

2 - Technical Overview

This section highlights the technical specifications and individual block components of the design. All design goals that we intended and were able to accomplice have been listed. Customers and potential buyers interested in this product can utilize the specifications listed here to determine whether or not the device will be able to meet a need of theirs.

Our specifications have been revised several times due to the scope and purpose of the project changing over the duration of its build. The changes are dramatic since the encompassing design objectives changed significantly. Because of this, both of our initial and final design iterations of our device's specifications have been provided provided below. Note that in our final specifications table, each highlighted portion indicates a specification that was developed and showcased in our design's final demonstration.

2.1 - Specifications

The initial design specifications are listed in the chart below:

Table 2.1: Initial Design Specifications

Specification	Description
Power	Powered by a standard USB connection and Rechargeable
Dimensions	Size of 30in x 15in x 16in
Accuracy	90%+ of trace elements discovered
Weight	Less than 5lbs
Cost	Less than $1000
PCB	Smaller than 10in x 10in x 10in
Detection Precision	Detects impurities as sparse as 10 parts per million
Optical Filtering	Detects the refraction rate of light within 400-700nm

The final design specifications are listed in the chart below:

Table 2.2: Final Design Specifications

Specification	Description
Power	Powered by a standard USB connection and Rechargeable at 5V and 0.5A
Mean Absorption for Each LED	Voltage Drop for each LED of 1.2V
Accuracy	90%+ of trace elements discovered
Mean Test Sample Response Time	30 seconds
Cost	< $1000
PCB	Should be less 10in x 10in x 10in
Concentration Detection Precision	Detects chlorophyll in concentrations as low as 10mg/kg

We demonstrate the following specifications in our design showcasing the mean absorption of each LED, mean test sample response time, and the chlorophyll concentration detection precision. Each of these were measured and tested directly during our final demonstration showcasing, and our testing steps were provided. The results of our final demonstration were used to compose the specs highlighted here.

2.2 - Hardware Block Diagram

The hardware block diagram shows the overall look and how the device will work on the hardware side of the spectrum. It demonstrates how each part of the device will interact with each other part of the device and the information will overall flow from one part of the device to another. It also demonstrates the roles that are gonna be used in the project by assigning each member a specific part of the hardware block diagram to focus on. Brief descriptions will be provided for each component here but specifics will be covered later in this document.

Like what was done for the design specifications, both the initial and final hardware block diagram details will be provided and outlines. Any specific changes made to the hardware block diagram as the final product fully matured will be mentioned in this section.

Figure 2.1: Initial Hardware Block Diagram

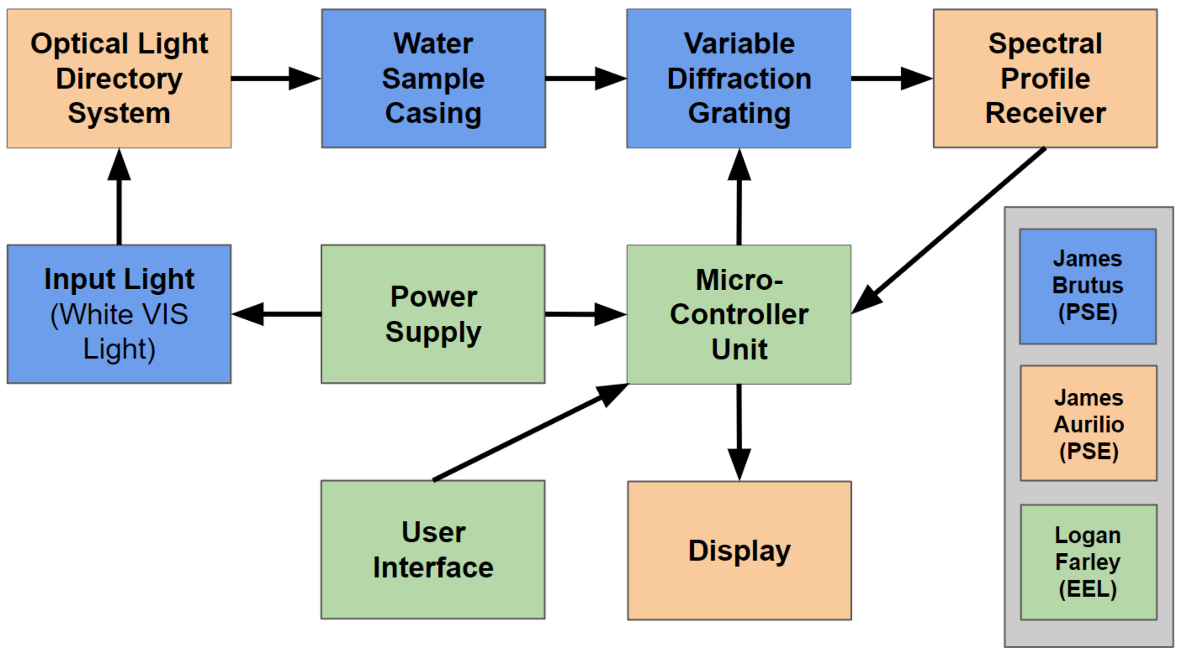
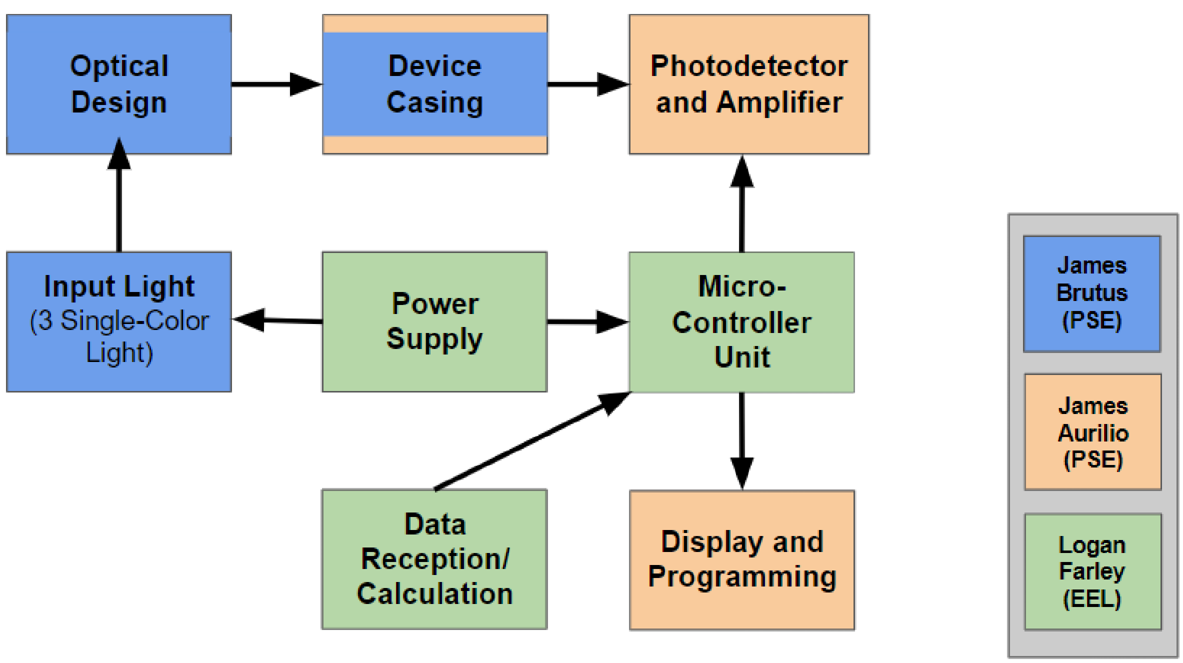


Figure 2.2: Final Hardware Block Diagram



The roles were decided by expertise in field and major. James Brutus and James Aurilio dedicated their efforts towards the optical components of the device. Throughout the designs completion, a considerable amount of interworking was done between each individual's realm of responsibility.

James Brutus was responsible for choosing the light source and diffraction gratings necessary to achieve workable absorption spectral profiles that will develop as a result of any specific impurities present in the provided water sample. Brutus dedicated time towards researching the spectrophotometry of common household water impurities to ensure the correct technical specifications of element absorption are met for this specific application. Once the switch away from a spectrometer design was determined, Brutus directed attention towards determining what type of impurity can be selected by a limited range of wavelengths in the visible light spectrum. Brutus then performed research in determining how chlorophyll, the selected impurity, could be identified with a set of preselected light emitting diodes.

James Aurilio was responsible for constructing the optical light directory system, spectral profile receiver, and display. In this, James Aurilio performed calculations involving the spatial and geometric manipulation of the light source; directing the beam towards the water sample and receiving it to obtain a snippet of transmitted and received light for analytical and post-processing purposes.

Logan Farley fabricated the design of the electrical hardware of the various components; the power source, user-interface, and controller unit. He was responsible for centralizing the individual components of the device into a singular working unit.

The interdisciplinary aspects of the project including whole concept design, device to software integration, calculations, financials, and part sourcing will be designated as group effort tasks. These were objectives that were accomplished by the group as a whole or by individual members who took on the responsibility for the various components.

2.3 - Hardware Block Descriptions

To help distinguish the necessary roles and purposes of the specific blocks that are described and shown in the above diagrams. The blocks are described with their purpose and overall description in the following paragraphs to distinguish in and help with part selection.

<u>Input Light</u>

The input light will be the primary light source for our design. We investigated the use of infrared and ultraviolet sources of light as potential contributors to our design, white light was considered to be utilized as our primary source. White light sources are typically low-cost and relatively easy to source as well as optical devices used to manipulate it. It is also very practical in our design as many common water impurities, such as aluminum and nitrates, experience absorption within the visible light frequency range. Visible light, also, has a truly large amount of research done on it, due to the cheap costs of LEDs, which have proliferated as a maturing technology to be used in advancing retail practicalities.

That being said, we ran into several issues in finding ways to accurately split white light into its component parts. We later determined that we could use a set of three LEDs with each emitting a narrow wavelength band of light at certain wavelengths. This was possible since we shifted our design objectives from being able to detect a range of impurities to just a single impurity, chlorophyll. It became unnecessary to incorporate a spectrometer design for this purpose.

The research greatly benefited our ability to use the light to direct our efforts in identifying impurities using relatively novel optical means. This light sources were ultimately directed towards our test sample. The spectral profile of the unaltered light source were compared to the light that passes through a set volume of impurities dissolved in aqueous solution. The comparisons ideally allowed us to identify some common impurities that influence the output spectral profile. We then investigated which wavelengths, intensities, and geometric properties of light will aid us in determining the most ideal light source. We concluded that three LEDs at 430, 505, and 660nm would best suit our needs for detecting chlorophyll dissolved in aqueous solution.

Optical Design

This component of the design involved any optical system that served the purpose of changing the properties of our chosen light source to maximize absorption experienced by the sample. A lens setup or fiber optic system was considered as well as the possible inclusion of optical filters, polarizers, and irises. These were determined depending on the scale of our design. Initially we considered this component to benefit from a dynamic design; one that changes depending on the impurity being scanned to maximize responsivity from the setup for accurate identification, but this proved complex and unnecessary to meet our matured design objectives.

The parameters of light output from this system (divergence angle, wavelength specific intensities, etc.) were taken into account when performing calculations based off of the spectral profile measured by the receiver. Two optical paths that split the input light in half to perform two measurements simultaneously was originally considered, but we decided, for simplicity’s sake, to utilize a single optical design that accomplished the benefits of two by requiring the use of both a test and control sample.

Water Sample

The water sample composed of a sample of water that is provided to the device by a user in a small optically transparent casing. The ideal sample is sourced from any building tap-water or outdoor, environmentally available, source. The exact volume, quality, and casing material of the water sample provided was determined to be 150.8ml which would maximize the accuracy of the device since that is what the device was tuned for. The objective is to accurately determine the presence of organic chlorophyll chemicals present in a provided sample while being flexible to other impurities or aberrations that may affect our measurements and calculations.

Other impurities could include the scattering and analysis of microplastics, or other common commercial impurities which may arise and have the opportunity to be optically found. A benchmark water source (likely distilled) is referenced against as a control sample to aid in determining the parameters of varying components of our design.

Light intensity and transmission through the control, which should have 0 concentrations of any impurities present, will be measured against to determine the exact amount of absorption that may be present in the independently provided water sample from the sample test water source.

Diffraction Component

The diffraction component of the design was intended to be used as a sort of filter before the optical receiver. Any light within the visible spectrum was supposed to be filtered and tuned to allow a specific wavelength of light to pass through to be analyzed by the receiver. Types of tunable diffraction components will be considered for our design and weights for determination, based on cost, efficiency, power-usage. Concepts for tunable diffraction elements include acousto-optic modulation, electro-optic modulation, liquid crystal diffraction gratings, diffraction grating wheels, prisms, or other elements.

Multiple static non-tunable gratings, selected based on ideal wavelengths needed to be analyzed to identify specific impurities, on an adjustable turnstyle defines the “diffraction wheel” concept. The parameters for each of the trace elements’ absorption spectra to be identified will be programmed onto the microcontroller. The parameters of this diffraction component was intended to change to accommodate each impurity’s specification, which in turn will be selected through the user-interface.

The diffraction component was completely limited in our final design as it was ultimately deemed unnecessary. Wavelength selection took place in the design phase, with the intention to detect chlorophyll. This is why multiple LEDs were utilized as distinct wavelengths.

Spectral Profile Receiver

The spectral profile receiver was intended to be the primary data collection point for our device. This component consisted of either a single adjustable photodetector or an array of photodetectors at set points along the diffused spectral axis. Said axis is defined as the line along which the diffraction element diffracts the different components of the output light from the source. The type and accuracy of the photodetector was determined based on the intensity of the light source we will be utilizing and the expected absorption.

Raman scattering, transmission, or fluorescence from potential impurities in our sample water sources, depending also on the type of process used. The data collected here will be used to perform our spectrochemical analysis calculations to determine the concentrations and identities of specific impurities in the sample.

Microcontroller Unit (MCU)

The microcontroller unit (MCU) is the computational source of the device. The microcontroller serves as the integration unit between the hardware and software components of the design. The software (outlined in our Software Block Diagram) is developed here. This device was intended to be responsible for tuning our diffraction grating component to prioritize necessary wavelength intensities to be measured by our photoreceiver unit which will be dependent on the particular impurity selected by the user in the user-interface, but this was deemed no longer necessary.

Software was intended to be coded onto the microcontroller unit to determine which diffraction settings and equations need to be applied to our measurements to perform spectrochemical calculations. Instead, the code simply referenced publicly known data regarding chlorophyll absorption properties to be able to accurately calculate concentrations based off of measured light intensity for each wavelength of light being transmitted.

The data measured was referenced against a preloaded database to chlorophyll impurities, and their concentrations, that may be present in the sample. The measured data and experimental deductions are output on the display unit of the device. The exact coding language was python, and it was determined due to the flexibility of the microcontroller unit selected for this design. The microcontroller was ultimately be incorporated into a holistic printed circuit board for the electrical components present within the design.

Display And Programming

The display is what shows the user the information generated by the device. The measured spectral profiles, detected impurities and their concentrations, and operating conditions of the device (power, sample loading, potential errors) are depicted here for the user to see. The display was initially intended to notify the user if the measured impurities are safe for human consumption, but this no longer applies since this specification no longer aligns itself with our design objectives.

It was considered for the display to be either analog or digitally based depending on the objectives of the design. We concluded with a digital design on an LCD display. All information loaded onto the display will be provided by the microcontroller unit. The display will not be interactive as all user input will be done through the user interface component of the design. It was intended for the user-interface to be integrated into the display. It was not integrated into the display since it provided no additional major benefits.

Power Supply

The power supply supplies energy to all active components of the device (light source, microcontroller unit, display, receiver unit, user interface). The power supply is low-powered, requiring no more than 5V to power the aforementioned components. Some components of the system will be powered via USB, that will send 5V at 0.5A, which in-turn can be connected to a standard 120V home wall outlet. This increases the overall convenience-of-use of the device, furthering the objective of practicality for retail use. The USB connects to a battery charger that charges the battery that powers the rest of the device.

2.4 - Software Block Diagram

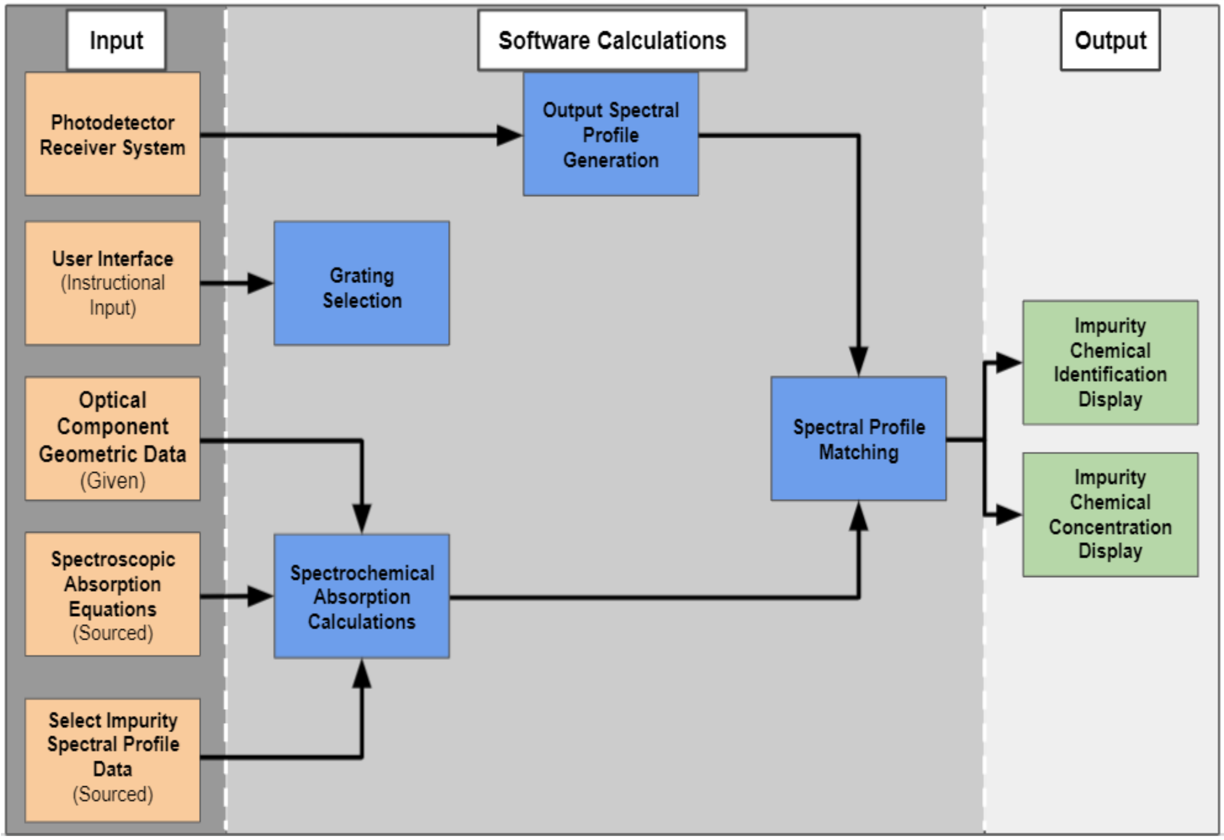
The software block diagram is to help the members explain the software side of the device. The device needs to be able to make specific calculations based on the input and display various information to the user. The software was coded in Python which is a language that can be read by our specific microcontroller unit. The language is important as the language set the boundaries for what we can and cannot do with the device.

For the things we decided to do, the chosen coding language made things fairly simple to process and export onto the display. The software block diagram helps visualize the connections between the input, software, and the output of the device labeled left to right in the diagram.

Individual duties for contribution towards the individual software blocks were not separated as was done with the hardware block diagram. The software components were each contributed towards by all members of the design team due to the equal footing each of us have in software development.

Reference the figure below for the separate software components:

Figure 2.2: Software Block Diagram



Blocks on the left are considered inputs that are either numerical givens or variables obtained from our measurement devices within the design. Central blocks are software calculation blocks based on Beer's Law theory. Blocks on the right is information our design is intended to provide for chlorophyll. A description of each block is cordially provided below.

2.5 - Software Block Descriptions

This section provides detailed descriptions of each of the software related components in our design. Our design accommodates each of these components as part of the end-product to ensure that project goals are met. It also outlines the primary input sources, calculations, and the output data our system is designed to manage.

Photodetector Receiver System

This component collects data measured by the photodetector to the microcontroller unit. The current produced by the photodetector is used to calculate the intensity of light on the receiving end. The information here is provided to the MCU as an input variable. This is the primary measurement tool for our design.

User Interface

This component delivers information to the user. There must be an interface for information to be given on an output end, or else this would not be anything but a theoretical device. The user interface delivers information concisely and with definitive results in mind. When we programmed the interface, it was important to keep in mind the user's desired information, and what it takes to get to that point. If we can reliably deliver results, then we can include only said results. If our product is in development, then the delivered results must be given with other functionality details for us to configure the system. This was programmed accordingly, per our stage of development. More details could have been rendered as part of the user-interface, and these details can be considered for potential future scalings of this design project.

Optical Component Geometric Data

This component is described as "given" because it is included in calculations as if it were a constant. These constants will be provided based on the solid-state optical components chosen in the foundations of the design: the lenses, intended gratings in the initial design concepts, etc. This is based on the geometry of our design, and is used to calculate measurements like the expected angle of the first order diffraction of light off of our diffraction element, as well as other items.

Most of this data is used to develop solid parameters for use in our Lambert-Beer Law equations. The volume of sample influencing a specified beam radius and trajectory of light play a heavy role in how our concentration measurements are determined.

Spectroscopic Absorption Equations

These values were intended to be known in order to calculate the concentration of impurities in a sample. It is important to note the importance of knowledge of the impurities that this device will be attempting to analyze. There are many different impurities in water that, according to authorities in health and safety, must be minimized in drinking water. Thus, these data points must be found and must intelligently populate a system of analysis for the determination of any of these impurities to be possible, especially using spectroscopy, which is not traditionally used in the area of water quality testing.

Grating Selection (LED Selection)

This component was intended to be utilized to select between grating elements in order to provide us with a better spectral picture of the impurity being discovered. It was supposed to decide the angle of a diffractive element, depending on the wavelength of light we desire to be propagated through the sample. It was also intended to be a trade-off between functionality and user ease for something like this to be implemented, as it may be implausible to have this automated. As mentioned, this component is no longer being utilized. Instead, our code will be dependent on the wavelength of light being emitted by one of three LEDs. This is covered later in this document.

Spectrochemical Absorption Calculations

This component represents the calculations utilized to find the concentration of given impurities. With givens in mind per certain impurities, we determined how to place impurities and their characteristics into the wavelength dependent absorption profile strategy we used. Without this, we would not be able to calculate anything. Again, this strategy is to exploit the wavelength absorption characteristics of impurities in aqueous solution by means of the Lambert-Beer Law.

Output Spectral Profile Generation

This component provides data for the final calculation regarding chlorophyll impurity detection. The spectral profile generation is a given integral component in any determination using a spectroscopy strategy. As it was noted earlier, understanding the spectral characteristics of the materials we are attempting to work with is extremely important.

Not only this, we should understand the spectral characteristics of anything and everything else involved in the system which might have bearing on the output spectrum. The glass that might hold a sample would be one example of something that could affect the system, and the input light source would especially be an important consideration. For these reasons, much care was put into the understanding of spectral profiles which are output from our system. The understanding of these profiles and the ability to configure them to obtain a proper analysis was invaluable to us.

Spectral Profile Matching

This was intended to be a part of the calculations used for spectroscopy. We will have specific spectral profiles that we will need to use for references in order to properly analyze a spectrum that is output from the sample.

As you know, spectroscopy was no longer used in our design. Instead, this component simply referenced the known wavelength absorption properties of chlorophyll and compared it to the absorption/transmission characteristics measured by our device.

Impurity Chemical Identification Display

This component uses the wavelength spectral profile matching technique that we coded to identify the impurity chemical and inform the user. It will do this by using the info gathered by the photodetector array and with the device’s which match the chemical compound that's in the water. Once identified the device informs the user the chemical compound of the impurity allowing the user to understand what is the water that they put into the device. The main purpose is to inform the user in an easy to read manner so that they know how much chlorophyll is in the water.

Impurity Chemical Concentration Display

This component is the part of the software that tells the user how much of the impurity is in the water that was analyzed. When the water is analyzed the device's software will compare the intensity of the wavelengths that are coming off the impurity to get an estimate of how much of said chemical compound is in the water. The software developed will then compare that estimate to the fixed value of the water sample, for this device it will be 150.8mL, and calculate the concentration of the impurity in the water sample. This information is then be displayed to the user as a voltage reading that is dependent on the amount of light that is transmitted through the sample for each of the three colored LEDs.

3 - Estimated Budget and Financing

In this section, we outlined our intended financial goals surrounding the design of this product. We also outlined the actual costs associated with the development of this product. This includes devices, components, that were purchased during the design process even if they were not implemented in the final product.

We will be providing our methods for determining the cost-benefit of specific product selections for integration into our device to meet these goals. Specific intermediate products determined for use in our design will be listed here and their expected costs will be provided to provide a general perspective and insight into the design's final product costs.

This section will include the determined House of Quality diagram as our marketing analysis tool and the estimated holistic project funding costs for specific components that will be integrated within the design. These items will be related back towards our initial project product description and goals: the intention being that the end product will be available for household and retail use.

The development of this project should cost no more than the amount displayed in the project funding table, however, we hope that once developed, methods will be uncovered to make the design easily scalable with quantity to hopefully reduce the costs for the design if made commercially available.

3.1 - Engineering-Marketing Analysis

It is important to analyze the cost-benefit to different specifications of projects in engineering to ensure focus is being kept on efficiency of cost and function. This helps to make sure that a product is viable in a marketing sense, which is essential to whether or not an engineer should even be working on a project or not. If the technology one makes, even if it is extremely effective at a purpose, does not justify that purpose with a reasonable financial cost, then there is no effect to that technology at all.

In this section, we will use a “House of Quality” diagram to determine the functions we will focus on and use this house of quality to make educated decisions on part focuses. Diagrams and considerations like these ultimately contribute to the ability to place small decisions, like those of individual parts of a system, within the big picture of the project’s function and cost effectiveness.

The House of Quality will show the engineering requirements, marketing requirements and the targets for the device’s specifications and how each has either a positive or negative correlation based on how it connects to that particular aspect of the engineering market.

To explain more what the actual signs mean, we will break down our diagram and its symbols for transparency. A positive correlation shows that the requirement of the engineering and market correlate to the specification by the group in a positive way, for example, that they work together. A specific circumstance of this happening could be the small size having a major positive correlation to safety and portability as the ability to carry the device and unlikeliness of someone to get hurt by a small device.
There may also be a negative correlation with this “small size” attribute and other attributes of the project that are being analyzed. A negative correlation between this and others could mean that the requirements of the engineering and market do not correlate to the specification by the group in a positive way, for example, they do not work together.

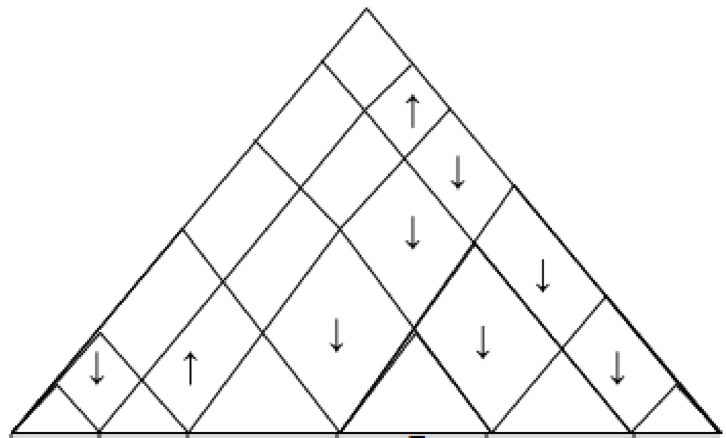
In the case of the size example, it has a negative correlation with the cost and detection threshold given the need for more portable or sensitive components, more fine measurements, and less space to resolve small wavelength bandwidths on a diffraction pattern. As the size gets smaller it is harder to create the device that has an accurate threshold, and so there is ultimately a negative correlation that is decided between these two aspects, which is decided with extended analysis and consideration to different variables.

A diagram like this, as you can now see, makes the many comparisons, considerations, and interconnections between all of these attributes portable for an easy big-picture tool for context. The size is also negative as the difference in materials that would be used pales in comparison to the potential extra difficulties of the need to have an advanced fabrication of the outside to fit the device. The equal sign shows no correlation. This is mostly used in cases where the requirements of the engineering and market do not correlate to the specification by the group in any meaningful way. The equal for the spectral range and ease of use is done because there is no meaningful way that the two aspects can be connected that aren't already done in the other aspects that are covered.

For more logic on said aspect itself, there would be no correlation between a user's ability to use the object and the inner workings of the object itself. Realistically, the user will only be involved in using the product's user interface, or the outside of the object, which is not necessarily connected to the project's function. There are also ways for the engineering aspects to relate to each other, which would lead to more considerations, thus there are correlative values at the top of the "house of quality".

One should keep in mind the interconnections of the engineering aspects before making decisions on any given subsystem in order to create a holistically sound and concentrated effective system. Otherwise, one would be making uneducated decisions within the grander scheme of the project, and the project's effectiveness in relation to its cost or effort to make would suffer.

Figure 3.1: House of Quality



House of Quality		Weight	Size	Spectral Range	Spectral Resolution	Energy Efficiency	Cost
		-	-	+	+	+	-
Safety	+	↑↑	↑↑	↑↑	↑↑	↑	↑↑
Ease of Use	+	↑↑	↑	=	=	↑	↑
Portability	+	↑↑	↑↑	=	=	=	↓
Detection Threshold	-	↓	↓	↑	↑	=	↓
Cost	-	↓	↓	↓↓	↓	↑↑	↑
		Less than 5lbs	Less than 30 x 15 x 16in	Detect the refraction rate of light within 400 - 700 nm	Detects impurities as sparse as 10ppm	Powered by a standard American wall outlet (120V 15A)	Less than $1000

The house of quality demonstrates the means for interfunctional planning and communications along the lines of product specifications and characteristics.

3.2 - Estimated Project Funding

All components that were anticipated to be purchased for integration into our design and their expected costs are listed here.

Item	Cost	Quantity	Total Cost
MCU	$30	1	$30
Display	$50	1	$50
PCB	$50	1	$50
Breadboard	$20	1	$20
Optical Array	$20	1	$20
Photodiode and Mount	$36	1	$36
Lens	$40	2	$80
Diffraction Grating	$20	1	$20
Mirror	$30	1	$60
Fiber Optic Light Guide	$80	1	$80
Power Supply PCB	$25	1	$25
Glass Vials	$10	1	$10
USB connectors	$2	2	$4
Misc Electronic Parts	<$50	TBD	<$50
TOTAL COST			<$530

3.3 - Actual Project Funding

All components that were actually purchased, for incorporation into the product at any point during the design process, are listed here. This includes unused items. A final cost row is also included, which showcases to cost of parts only utilized in the final product.

Item	Cost
MCU	$33
Display	$50
PCB and Power	$85
Breadboard	$25
Chlorophyll	$72
Photodiode and Mount	$142
Lens	$173
Diffraction Grating	$21
Mirror	$31
LEDs	$89
Glass Vials	$34
USB connectors	$4
Misc Electronic Parts	$50
TOTAL COST	$622
TOTAL DESIGN COST	$809

The total cost estimate was calculated by removing costs associated with the gratings, original lens set, and phototransistor components that were replaced in the final design.

4 - Project Management Timeline

This section covers the project progression timeline that our team worked towards abiding by throughout our design process. This timeline was meant to ensure that consistent effort is being dedicated towards project completion throughout the project's lifetime. Any mishaps that cause the team to fall off of this expected timeline called for a group discussion and a reevaluation of the tables below. Increases in effort were dedicated towards the project to make up for lost progress at several points during the design process.

4.1 - Project Milestone for Fall 2021

Task	Duration	Date
Group Selection	1 week	Aug 13 - Aug 19
Initial Project Idea Submitted	1 week	Aug 20 - Aug 27
First Divide & Conquer Draft	3 weeks	Aug 28 - Sept 17
Updated Divide & Conquer Document	2 weeks	Sept 18 - Oct 1
Research on Part Selection	2 weeks	Oct 2 - Oct 16
Meetings with Advisor	1 week	Oct 17 - Oct 23
45 page report	2 weeks	Oct 23 -Nov 5
Meetings with Advisor	1 week	Nov 6 - Nov 11
Updated report with feedback	1 week	Nov 12 -Nov 19
90 page report	2.5 weeks	Nov 20- Dec 7

The table above outlines our group timeline goals for the Fall 2021 semester in accordance with the course specifications and requirements for OSE 4951 and EEL 4914 Senior Design 1. The highlighted sections required submissions where the design reports were reviewed and feedback was administered.

4.2 - Project Milestone for Spring 2022

Task	Duration	Date
Purchase/source materials required for design that weren't needed for the alpha phase	4 weeks	Dec 3 - Dec 31
Build the device in the initial prototype	2 weeks	Jan 1- Jan 14
Test components that come with the device to ensure preliminary specific	1 week	Jan 14- Jan 21
Design and write needed software	2 weeks	Jan 22 - Feb 5
Integrated needed hardware and tweak/revise software as needed	5 weeks	Feb 6 - Mar 12
Midterm Demo	2 Weeks	25 March
Integrate design decisions into the final product	4 weeks	Mar 12- Apr 10
Testing of the final product design	1 week	Apr 11 - Apr 17
Any additional documentation	4 days	Apr 18- Apr 21
Final Demo	1 week	Apr 22
Compilation of all documents onto website	1 week	Apr 29

The table above outlines our group timeline goals for the Spring 2022 semester in accordance with the course specifications and requirements for OSE 4952 and EEL 4915 Senior Design 2. The highlighted sections required submissions where the design reports will be reviewed and feedback provided.

5 - Technical Background and Research

In this section, dive into the technical realms that our design is expected to remain within. We outline and incover current technologies that either serve the same purpose as, or use similar techniques as our own design to provide the reader with context surrounding the device. We will also be outlining the physical and theoretical sciences that will need to be accounted for in the design process.

Many of these devices utilize spectroscopy concepts which our initial designs were intended to mimic, but they still serve the same purpose of identifying the concentrations of impurities in aqueous solutions. We include them here to showcase potential competitor products. Our device is essentially an over-simplified version of some of these devices that comes with the benefit of decreased cost.

5.1 - Current Technology Investigation

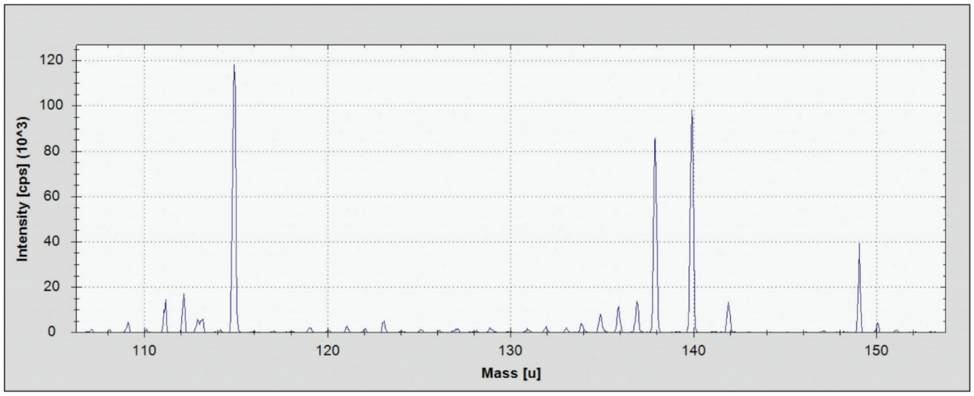
Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Inductively coupled plasma mass spectrometry is a destructive chemical analysis technique that measures the elemental composition of a sample by using plasmas to break down a sample into its respective ion fragments. The ions are accelerated through a mass analyzer allowing for an accurate detection of most elements in the periodic table with a single test with detection limits on the scale of nanograms per liter. This method, however, due to its destructive nature, does not capture compound information as compounds are split into their respective components during the inductive plasma analyzation process, however, potential compounds present in the original sample can be reverse engineered.

Figure 5.11: Inductively Coupled Plasma Mass Spectrometer

The method employed by inductively coupled mass spectrometers is an intensive process requiring extreme precision in its engineered components. The use of devices like this are reserved for industrial tests and the cost of the machines themselves range between the tens to hundreds of thousands of dollars including periodic maintenance and part-replacement costs.

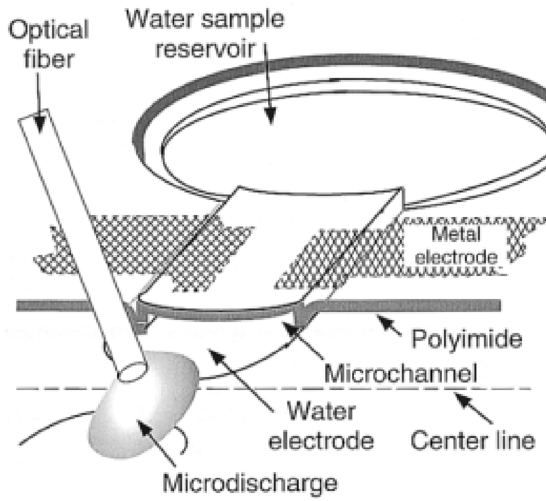
Figure 5.12: Sample Absorption Spectra Produced by Mass Spectroscopy



Liquid Electrode Spectral Emission Chip (LEd-SpEC)

The liquid electrode spectral emission chip utilizes spectrometry for impurity identification but instead of calculating absorption of a compound by first measuring the amount of light transmission through a sample, this device sends a current through a sample to excite the varying impurities within it. When excited, the impurities emit a micro-glow radiation that is coupled through a fiber-optic cable and coupled onto a receiver. The same way elements and compounds each have a signature absorption wavelength range and coefficient, they also have similarly differentiating emission bands that they emit when their electrons are excited to upper energy levels. This device exploits that property to identify them.

Figure 5.13: Liquid Electrode Spectral Emission Chip



These chips are relatively small in comparison to our design plans (approx. 1 mm in length) and they require very low power for use. This makes them fairly cheap, however, these chips must be integrated into a larger computing operating system for any practical applications, like water impurity identification, to take place. They are not standalone devices, which is something we plan for our device to be.

Hach - Water Impurity Spectrophotometer

This device, unlike the others, is most similar to our expected final product. It uses a technique most common to the technique we will be using in our design, spectrophotometry in the VIS wavelength range and it is approximately the same size in terms of household convenience. This device generates an absorption spectrum ranging from 320 - 1100nm (UV-NIR) and incorporates digital data depiction displays and allows for the input of custom user settings. It also has ethernet, bluetooth, and RFID features, making this device a smart device that is more convenient and user friendly than our own design. However, these added features come at a cost as this device is worth well over $6,000.

Figure 5.14: Lab-Intended-Use Water Impurity Spectrophotometer

The Hach water impurity spectrophotometer is a device intended for lab use, not retail use. We plan to create a similarly functioning device that may be less accurate and less incorporating of peripheral components (ethernet, elaborate GUI, etc.) meant for ease-of-use that is still able to achieve the purpose of detecting some common household tap water impurities.

The goal is to recreate a device, similar to Hachs, for use at the retail level; so, effort will specifically be placed into the fiscality of our design. We hope to produce a similar product to this in a cost effective manner. We understand that this will likely result in decreased design capabilities. That being said, our design will still be intended to be as applicable as possible for the average household.

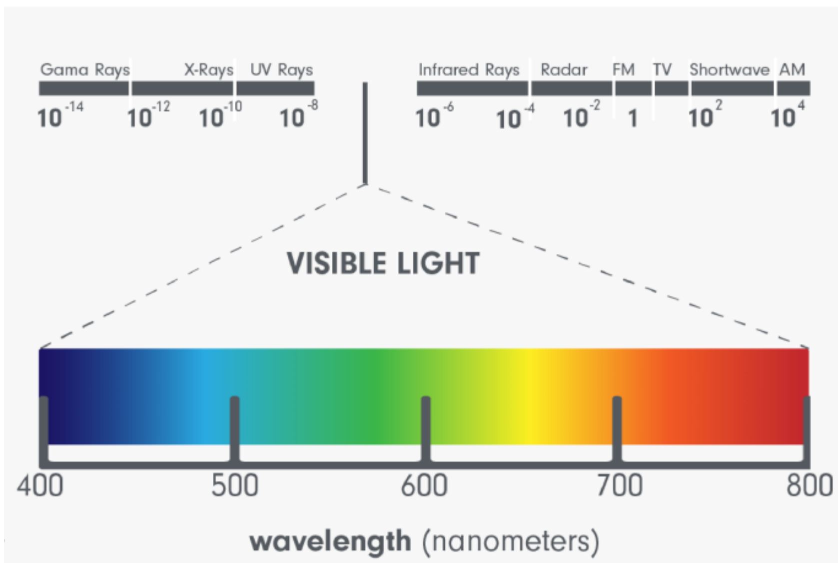
5.2 - Spectrophotometry

Our design was intended to rely heavily on spectrophotometry concepts. Spectrophotometry is the chemical identification of substances based on the intensity distribution of light that passes through a sample. Spectrophotometric devices typically use a broadband source of light that is then separated into its component parts by a diffraction grating, prism, or other diffraction techniques/devices. Select wavelengths are then directed towards a sample and control substance. The transmittance of specific wavelengths are compared between the control substance and sample to identify the influence on intensity impurities may have on the transmittance of a specific wavelength.

Information gained here is used to identify the absorbance spectrum of impurities within the sample which can be cross-checked to pinpoint specific chemicals that have matching absorption profiles. This quantitative technique has applications in physics, chemistry, biology, and material engineering and it will be the main photoptic technique applied within our design.

In some spectrophotometric devices that are limited to narrow electromagnetic transmission and detection ranges (i.e. just the visible spectrum, 380-750 nm), reagents are applied to bring the sample's chemical absorption spectrum to a specified window for detection. Reagents are often 'colorless' and are chosen to experience negligible absorption in a wavelength range, but when paired with a chemical impurity, they bring the absorption wavelength to a value distinguishable by the device. This ultimately causes them to 'dye' specific impurities to distinguishable colors that can be measured by an otherwise limited spectrophotometer.

Figure 5.2: The Visible Spectrum



5.3 - Wavelength Dependent Absorption Profiles

The product we have created ultimately utilizes the wavelength dependent absorption properties of chlorophyll to detect its presence and concentration when dissolved in aqueous solution. We essentially optimized chlorophyll's expected spectral absorption profile to bring emphasis to a few segments that we could exploit with select colored LEDs. Instead of looking at the entire absorption spectrum of chlorophyll, we only look at portions of the spectral profile that are considered peaks, or are in high contrast with other expected impurities.

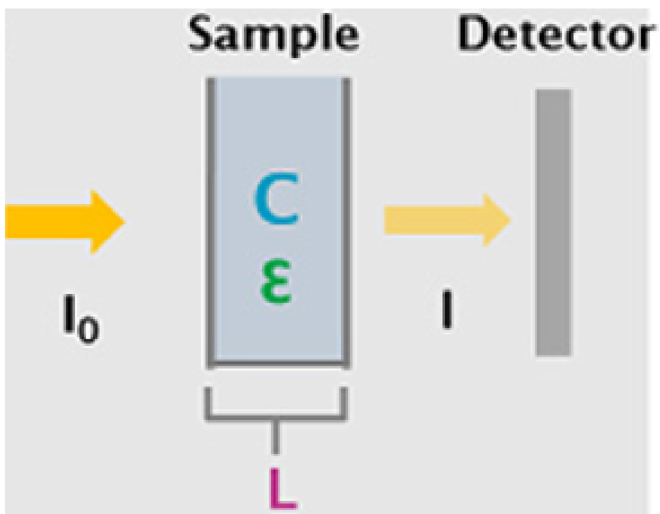
5.4 - Quantitative Analysis

This section will outline the varying theories and mathematical formulas that are relevant to our design. Specific equations and relationships between varying optical processes are listed here.

<u>Lambert-Beer Law</u>

To determine sample concentration, transmission first needs to be calculated. Transmission is calculated by measuring the ratio of light entering a sample vs. the amount of light exiting. Transmission or transmittance (T) can be represented by the following equation $T = I/I_0$ where I is the intensity of light input from a source (the photo-LED) and I_0 is the intensity of light after passing through the sample (measured by the photoreceiver). Absorbance (A) of the sample is then calculated by the following equation $A = \log(1/T)$. This can then be compared against the absorbance of specific compounds as determined by the Lambert-Beer law, where $A = CL\varepsilon$, where C is the concentration of a substance, L is the optical path length, and ε is the extinction coefficient that changes specific to a substance at a set wavelength. Some of these variables are integrated in the design to be known beforehand.

Figure 5.41: Lambert-Beer Law Geometric Outline



Our system was designed to obtain quantities for absorption (A). The optical path length (L) is a value given by our selected sample container which is 30mm. The extinction coefficient will be pulled from a preloaded database for select impurities we wish to identify. Obtaining an absorption spectrum of a sample will allow us to determine which select substance extinction coefficients to select given the absorption encountered at specific wavelengths and an understanding of which impurities are most common in our selected sample. This leaves C, the concentration of the substance, which the final design is tuned to calculate for the user.

Equations:

- $T = I/I_0$ — T: Transmission, I: Output Intensity, I_0: Input Intensity
- $A = \log(1/T)$ — A: Absorption

- $A = CL\varepsilon$ C: Concentration, L: Impurity Length, ε: Extinction Coefficient

Optoelectronics

This section outlines the methods we employed to convert electrical data produced by our hardware into optical data for use in calculations by our MCU to determine light intensity values. Before we can determine sample concentration, our system is to measure the intensity of light being incident on the sample containing impurities vs. the amount of light that is transmitted. This information will be calculated using data collected by the photodiode. Our input light source will be coupled through a 50/50 split fiber; one being transmitted through a test distilled sample (I_0) and the other through the impurity sample (I). Since we will be utilizing a photodiode or phototransistor as our light receiving source, I_0 and I will be calculated using equations regarding specific phototransistors, which will be more explicit with a given phototransistor element that will be chosen later. It is, however, helpful to keep in mind the nature of phototransistors and LEDs. Some equations regarding phototransistors and the current caused by incident light allowing for the recombination of electron-hole pairs are as follows:

Equations:

- $I_{ph} = e\eta_i TP_0(0) / (hv) [1 - exp(-aW)]$ I_{ph}: Photocurrent, e: electron energy, η_i : internal quantum efficiency, T : transmittance, P_0 : optical power, h : plank's constant, v : frequency, a : optical attenuation coefficient, W : width of depletion region

Geometric and Fiber Optics

Our design concepts rely heavily on the use of lenses and apertures to direct and manipulate light to optimize efficiency within a confined space. We were primarily concerned with the general collimation, longitudinal beam widths, and focal points of our light in our design to ensure that peripheral calculations (i.e. to determine light intensity and absorption) are kept consistent. The following geometric optic equations were applied throughout the optical portion of our design:

Equations:

- $\phi = (n_1-n_2)/(n_0)*[(1/R_1)-(1/R_2)]$ ϕ: Optical Power, n: Index of Refraction
- $1/f = (1/z)+(1/z')$ z: Object Distance, z': Image Distance
- $R = 1/f$ f: Focal Length, R: Radius of Curvature

Diffraction

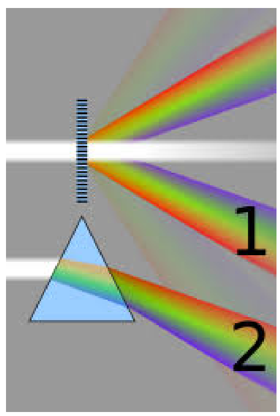
The concept of diffraction was intended to be exploited to deconstruct our initially broadband light source into its component parts. Although there are varying methods to achieve this, we initially planned to utilize the concept of diffraction achieved by diffraction gratings, as it was considered the most likely candidate to be utilized in our design. Common diffraction grating equations have been listed below. A complete spectrum can be observed for n=1.

These equations, however, were never utilized since we decided not to utilize a broadband source of visible light. Instead, three distinct wavelengths, particularly chosen to emphasize the wavelength absorption properties of chlorophyll were chosen. This eliminated the need for the use of any diffraction and spectrometer components.

Equations:

- $n\lambda = d\sin(\theta)$ — n: Mode, θ: Angle of Emergence
- $d = 1/N$ — N: Grating Constant, d: Distance Between Slits
- $y = m\lambda D/d$ — y: Displacement From Centerline Intensity; m: Mode, λ: Wavelength, D: Screen Distance

Figure 5.42: Diffraction Induced From Grating (1) and Prism (2)



Along with transmissive gratings shown in part 1 of Figure 5.6, there are also reflective gratings. Reflective gratings tend to be a bit more convenient as they can also better angularly direct the diffracted light, which were considered to potentially prove to be useful in our design.

Fig. 5.43: Reflective Gratings

5.5 - Selected Impurities for Device Integration

Every chemical compound and element has its own unique absorption profile. We will be looking at the absorption profiles of key inorganic and organic (chlorophyll) compounds commonly found in home tap water or environmental ecosystems to select impurities that our device will be tuned to identify. We will be prioritizing impurities that are common and identifiable within the visible spectrum only. Although incorporating the UV and IR range will allow us increased accuracy in identifying compounds, we were constrained by the costs of UV and IR photon emitters. Incorporating these ranges would have brought our design outside the scope of use as it would no longer become a cost-effective way to identify impurities. Retail use of our product is a goal that will be heavily considered as we select specific impurities our device is meant to identify.

Impurities that are considered common enough in tap water systems for integration into the scope of our device have been included in the table below. Their respective peak absorption wavelengths, primarily in the visible wavelength range, are also provided. Lastly, our reasons for selecting these compounds/elements and key features about them are listed below the table.

Table 5.5: Chemical Impurities

Chemical Impurity	Molar Mass	Peak Aqueous Absorption Wavelengths	Expected Color
Visible Spectrum: (N/A)	-	395-680 nm	-
Potassium Permanganate: ($KMnO_4$)	158 g/mol	310, 530 nm	Pink
Chromium (III) Oxide: (Cr_2O_3)	152 g/mol	300, 420, 580 nm	Light Green
Fluoride Chrysin Complex: ($F^- + C_{15}H_{10}O_4^+$)	273 g/mol	371 nm	Green
Iron Thiocyanate: ($Fe^{3+} + SCN^-$)	230 g/mol	475 nm	Orange-Red
Chlorophyll A	893.51 g/mol	420, 660 nm	Green
Chlorophyll B	907.47 g/mol	470, 640 nm	Green

Sodium Copper Chlorophyllin	724.15 g/mol	420, 650 nm	Green

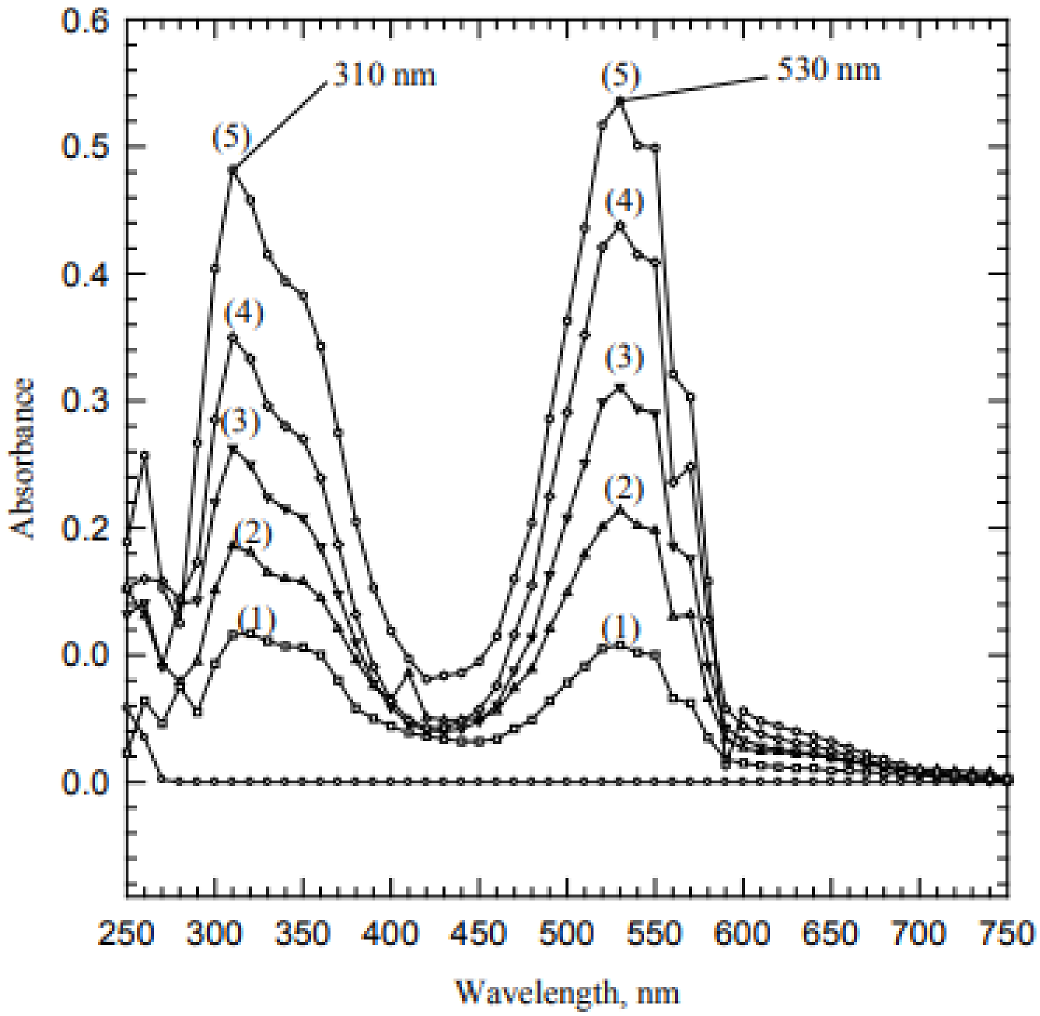
Specifics on each of these chemical impurities are listed below. The information provided will allow us to calculate the molar density based on weight and expected absorption ratios for use in our spectrochemical profile matching software section. Each one of these chemicals can also be readily artificially added to a control water sample source to test the functionality of our design.

Although we researched all of the listed chemicals, we tuned our device to identify only chlorophyll. The final three items listed in the table above were the exact chemicals considered when developing our device. The initial four were impurities that were initially considered, but due to the ability to utilize a wide range of wavelengths through the incorporation of a spectrometer design, we simplified our device to detect just chlorophyll which can be identified using a few select wavelengths. More information is provided below.

Potassium Permanganate

Potassium Permanganate is an oxidizer commonly used as a water treatment chemical to remove iron, manganese, and hydrogen sulfide from drinking water at temperatures ranging from 50-72℉. However, in excess, the chemical is considered a poisonous skin irritant. When dissolved in water, the chemical gives off a pinkish tint as it absorbs wavelengths peaking at 310 and 530nm. The absorption spectra of dissolved potassium permanganate in water is provided below:

Figure 5.51: Potassium Permanganate Absorption Spectrum (250-750nm)

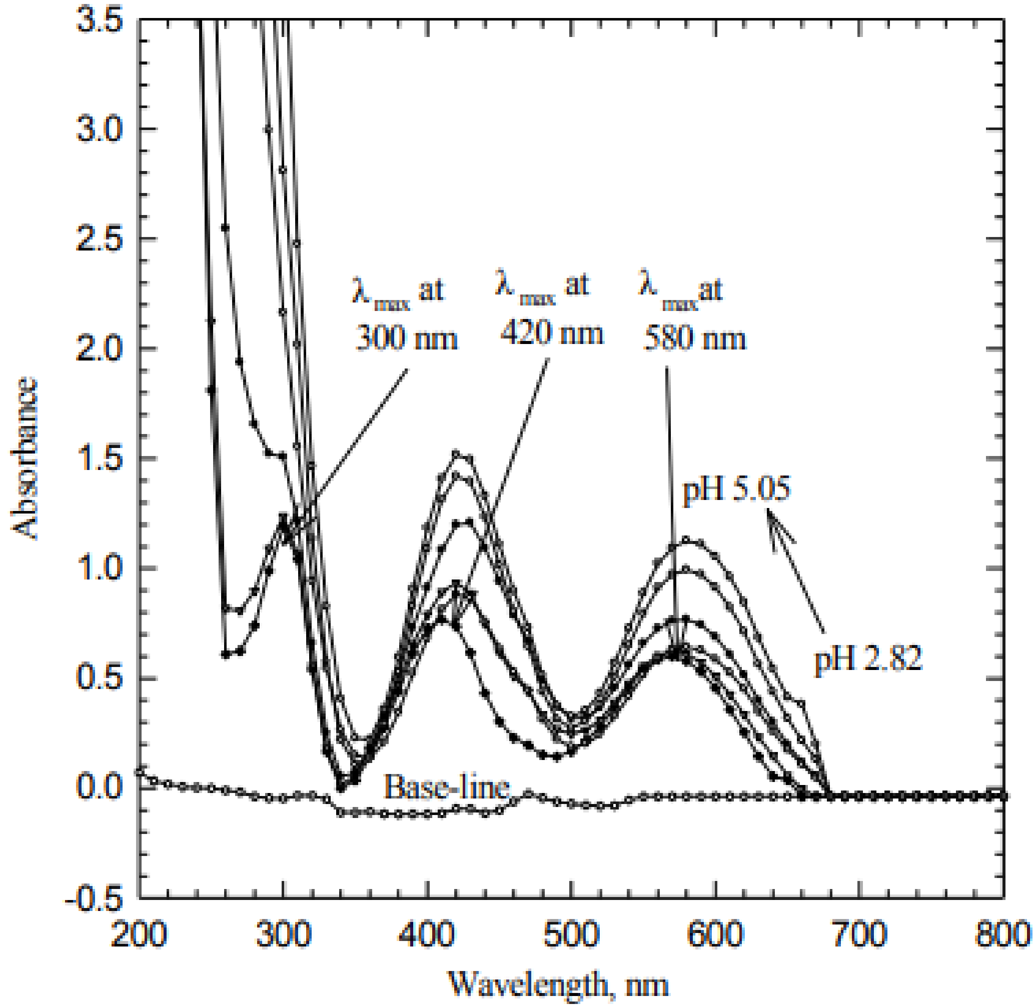


The absorbance ratio of Potassium Permanganate at varying molar concentrations (1 → 5 , lowest → highest concentration). Note that regardless of the concentration, there are absorbance peaks at set wavelengths. Applying the knowledge of the whereabouts of these peaks can be used to identify the substance if all other potential variables are eliminated.

<u>Chromium (III) Oxide</u>

Chromium (III) oxide is an inorganic compound with the chemical formula Cr_2O_3. It is soluble in water, and, if ingested, it may cause gastrointestinal irritation. The compound, when dissolved, dyes the water to a light green tint as it absorbs wavelengths of light peaking at 300, 420, and 580nm. The absorption spectra of chromium (III) oxide is provided below:

Figure 5.52: Chromium (III) Oxide Absorption Spectrum (200-700nm)



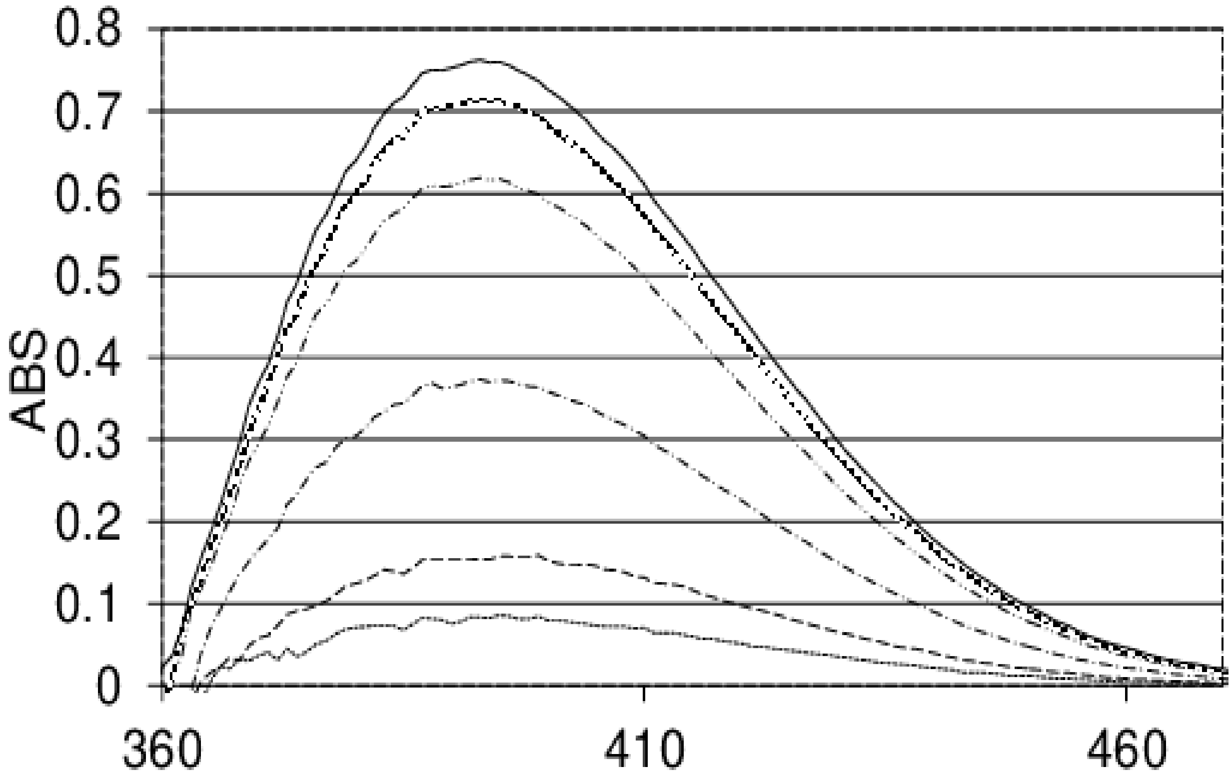
Chromium (III) oxide has three distinct absorbance peaks or rises within the visible light spectrum. These specific peaks can be used to identify it in a distilled water source when the correct reagent is applied. Although we will not have access to the UV range, it is still important for us to note the steady increase in absorbance from 350nm downward. We may or may not be able to detect that trend, unfortunately, due to limited input signal bandwidth.

Fluoride Chrysin Complex

Fluoride, F^-, is a very common water impurity and can be found in almost all sources. Depending on the concentration present in drinking water, fluoride can have either beneficial or harmful biological effects on consumers. These effects range from preventing dental cavities to fluorosis when excessive exposure is encountered.

Fluoride by itself is completely clear in the visible spectrum when dissolved in water. However, fluoride in drinking water is easily identifiable using spectrophotometric techniques by incorporating complexes of chrysin. The reaction of fluoride with specific complexes causes the sample to experience a color change that can be exploited to determine its concentration. The molar absorptivity for the fluoride chrysin complex has a peak absorption value in the visible wavelength at 371 nm.

Figure 5.53: Fluoride Chrysin Complex Absorption Spectra (360-460nm)

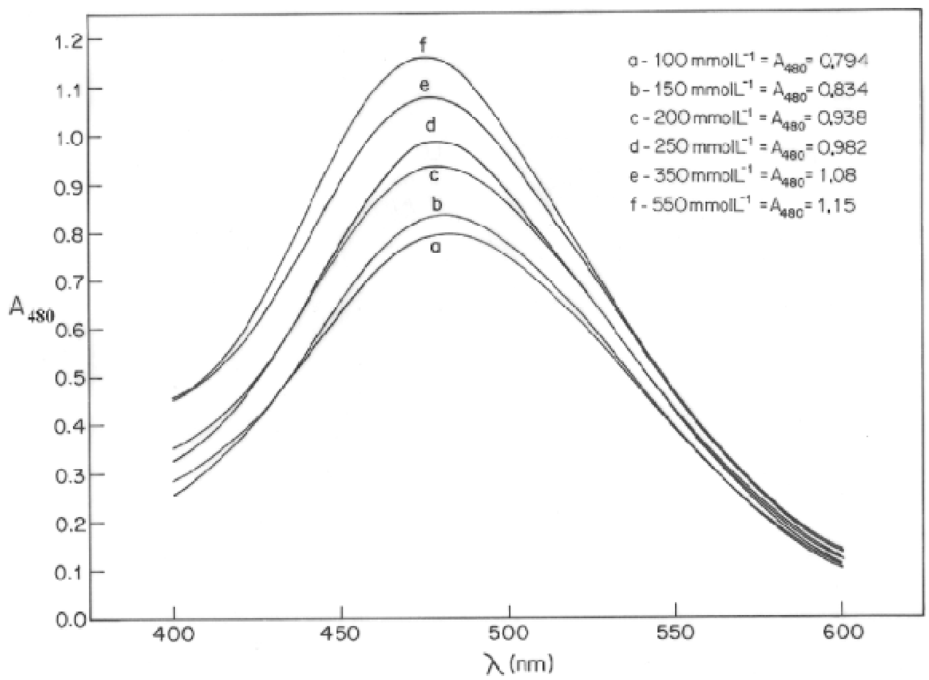


The Fluoride Chrysin Complex seemingly only has a single absorbance peak at approximately 371-390 nm. Because of this, it may be worthwhile to examine the rate of increase or decrease of the absorbance ratios at each end of the spectrum. It is a notable detail to take into account the more steep absorbance ratio at the smaller wavelength ranges (left side of the peak wavelength) than the larger ranges (right side of the peak wavelength).

Iron Thiocyanate Complex

Iron, F^{3+}, is another common water impurity found in home tap water systems. An excessive iron concentration ingestion can lead to diabetes, hemochromatosis, and nausea. Although iron ions by themselves in water can only be detected with UV spectrophotometry, when combined with the reagent thiocyanate (SNC^{-}), the iron complex becomes orange-red colored, allowing it to be identified using VIS spectrophotometry. The complex has a peak wavelength absorption at 475 nm as depicted by the absorption spectral graph below:

Figure 5.54: Iron Thiocyanate Absorption Spectrum (400-600nm)

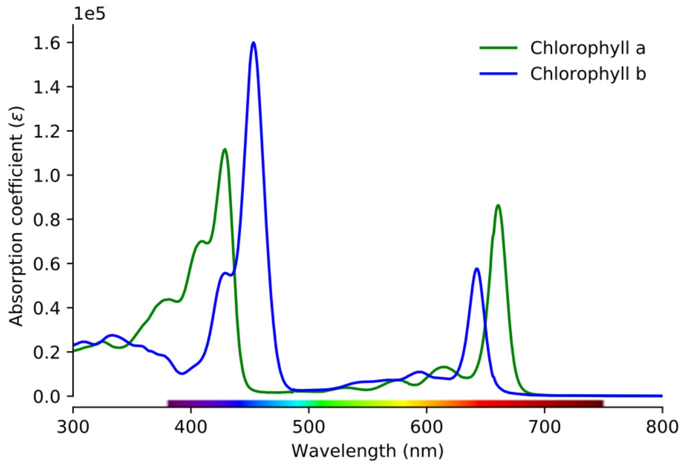


Like the Fluoride Chrysin Complex, Iron Thiocyanate has only one absorbance peak in the visible wavelength range at approximately 475 nm. Unfortunately, there is no major characteristic in the absorption pattern that can be visually identified. In comparison to our other 3 set impurities, the absorbance profile here may be differentiable enough by the peak wavelength alone, allowing us to pinpoint it.

All of the above selected impurities are differentiable from one another to identify with a simple diffraction / Lambert-Beer Law experiment which is why we chose them as starters for our design. They are also regularly found in home tap-water systems. The only downside is the use of reagents to bring some of the impurities' absorption wavelengths to the visible spectrum.

Chlorophyll A and Chlorophyll B

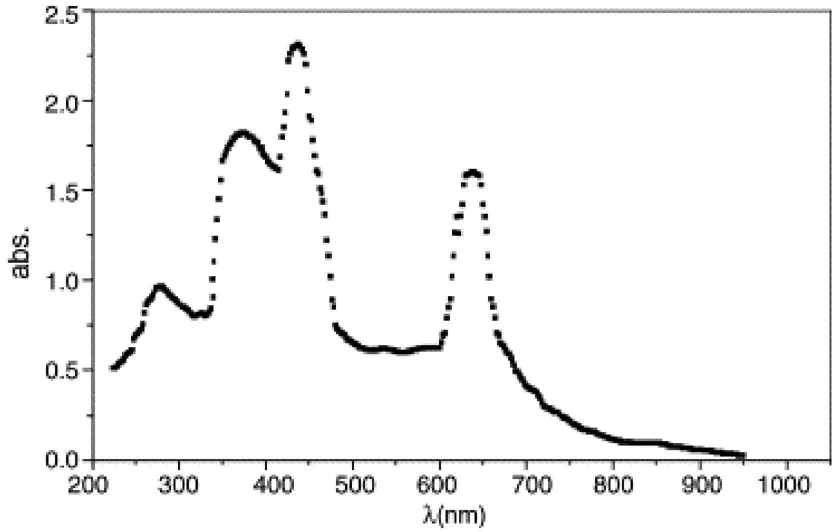
Figure 5.55: Chlorophyll A and Chlorophyll B Absorption Spectrum (300-800nm)



Chlorophyll A and B are organic compounds found heavily in plants and other living organisms that utilize photosynthetic processes to survive. The relative absorption spectra, in the VIS spectrum, of Chlorophyll A and Chlorophyll B are depicted in the figure above. This was the spectral profile that we referenced when considering which LED wavelengths we intended to use. You can see quite clear distinctions between the two absorption profiles of each impurity. The diodes selected emit light at wavelengths that maximize the absorption effects of both Chlorophyll A and B but also provide enough bandwidth to allow the device to differentiate between the two if both substances are present in a single sample. For example, the red LED at 660 nm was selected due to the high absorption of Chlorophyll A in contrast to Chlorophyll B which has practically zero absorbance at that wavelength. Due to the broadband nature of our LED, however, which emits light in a range of approximately 30-40 nm, we can still detect absorption effects of Chlorophyll B using the 660nm red LED. We only need to take into account the varying wavelength output intensities of each selected LED, which were provided in the device data sheets.

Sodium Copper Chlorophyllin

Figure 5.56: Sodium Copper Chlorophyllin Absorption Spectrum (200-1000nm)



The spectral profile that we referenced when considering the fine tuning of our quantitative analysis of the absorption intensities measured in our design was that of sodium copper chlorophyllin. This was the most readily available type of chlorophyll we could access to perform our tests to develop the design specifications. We could not utilize Chlorophyll A and Chlorophyll B impurities since they were abnormally expensive, ranging from \$300-\$400 from scientific commercial providers for just a few millimeters of it in concentrated vials. The absorption spectra of sodium copper chlorophyllin, however, resembles that of the merged Chlorophyll A and Chlorophyll B impurities, which still allowed us to perform some identification measurements, although, in a limited capacity.

6 - Part Selection Investigation

The Part Selection Investigation section of our report will essentially outline the various components of our design that required detailed cost, efficiency, benefit, and utilization analysis before being selected and integrated into our final concept design. Here, for specific objectives needing to be accomplished, we list specific techniques and products that will allow us to achieve a set design objective.

From here, we compare and contrast various competing products and/or design concepts in terms of feasibility, cost, and alignment with the general scope of the project to determine a specific candidate for integration into the final design. We then provide the specifications and expected costs of each component selected which will be finalized and condensed in Section 7, Part Integration, with the respective design schematics.

6.1 - MCU

The Microcontroller Unit (MCU) is one of the most important parts in the device, with it being the central core of the Printed Circuit Board and being the entire compunital part of the device. MCUs come in various different forms and with various different features that make sure one will be able to meet the aspect of our project no matter what it will have to do potentially. However, the MCU must be selected very carefully as it must be able to do very specific things, such as control as very specific aspects of the device. So the MCU must be able to do what we need it to do for project success. The MCU will ultimately be integrated into the main printed circuit board.

The main things the MCU must do is able to handle and compute the input from the the photo array that will collect the reflected light from the water sample, compute the information from the input and compare it to the information that we have gathered from our research and lastly be able to display the information to our display device.

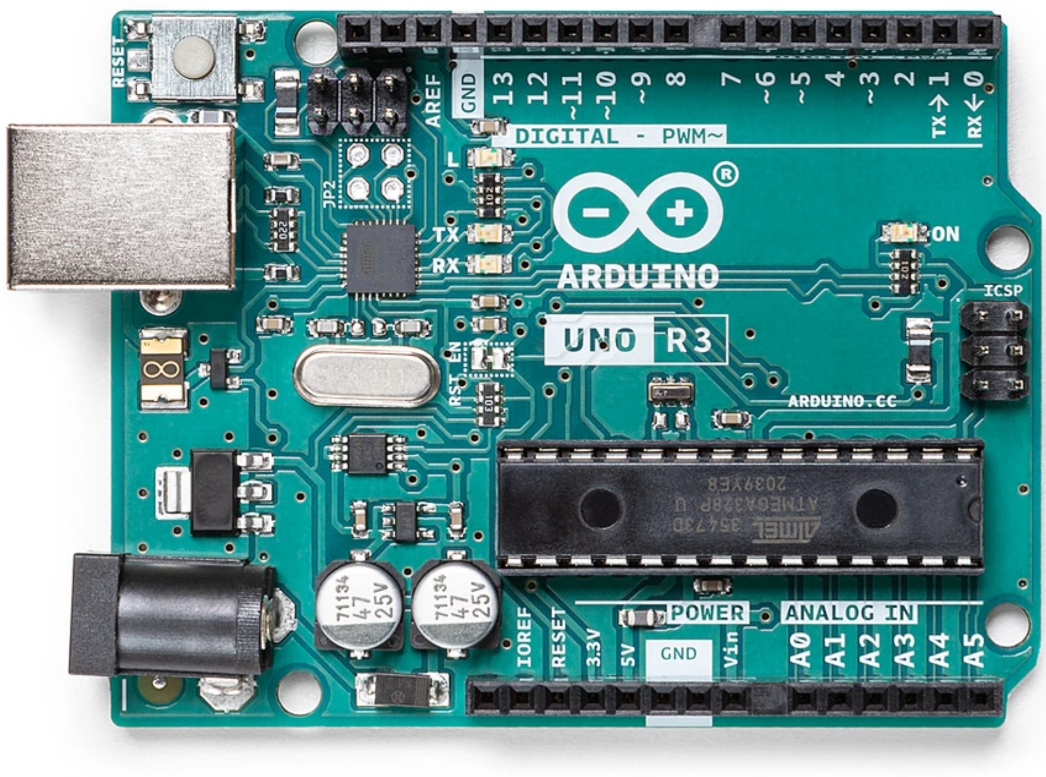
These are of course oversimplified so that it is easier to select parts, nonetheless, these are the bare minimum that the MCU must be able to do if the MCU cannot do these specific parts it cannot be used. However, we do not want the MCU to be able only to do the bare minimum things. To help select the MCU even further more generic aspects will be weighed such as how much power does it draw, will it fit in the device, how much does it cost, how easy is it to implement in our current and potential future design, and finally the most important aspect of the MCU is the availability in the market. If the MCU is unable to be bought then there is no reason to consider it being used.

With these aspects in mind some MCU come to mind with some preliminary research, these three are Arduino UNO, Raspberry Pi Pico, and MSP430FR6989. Each of these have specific advantages and disadvantages; these will be explored in the following couple of paragraphs.

Arduino UNO

The most common MCU used in the Arduino family of MCUs. Developed by Arduino it is described as a beginner friendly board with open source software. The current version of the board is Arduino UNO Rev3. It has 14 digital input/output pins (6 being PWM outputs), 6 analog inputs, 16MHz clock speed,an operating voltage of 5V and 13 built LEDs. With a size of 68.6mm x 53.4mm(2.7in x 2.1in in imperial). A huge advantage of Arduino UNO is the ease of access, with Arduino creating a simple to use software to program the board and built-in USB connection making it easy to connect to with existing wires and connection that we have. The biggest disadvantage that Arduino has is the price with the MCU being listed at €20,00 ($23.11) means that it will be a large cost investment up front, especially with backup reasons buying multiple boards will be most likely necessary.

Figure 6.1 : Arduino UNO Microcontroller



The Arduino UNO microcontroller shows to be a promising selection for our design. We are prioritizing an MCU that is cheap, small, and able to compute simple mathematical calculations. All MCUs listed are small and computationally-to-par, so one of the specifications that we will be prioritizing is costs, when comparing to other options. We listed its specifications in the table below for quick referencing.

Table 6.1: Arduino Specifications

MICROCONTROLLER	ATmega328P
OPERATING VOLTAGE	5V
INPUT VOLTAGE (RECOMMENDED)	7-12V
INPUT VOLTAGE (LIMIT)	6-20V
DIGITAL I/O PINS	14 (of which 6 provide PWM output)
PWM DIGITAL I/O PINS	6

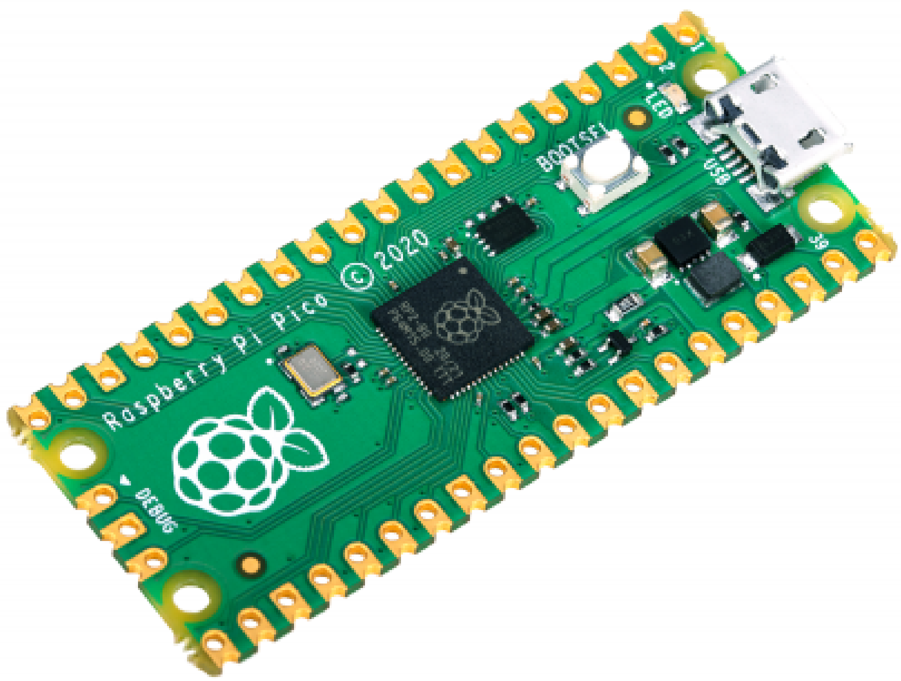
ANALOG INPUT PINS	6
DC CURRENT PER I/O PIN	20 mA
DC CURRENT FOR 3.3V PIN	50 mA
FLASH MEMORY	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
CLOCK SPEED	16 MHz
LED_BUILTIN	13
LENGTH	68.6 mm
WIDTH	53.4 mm
WEIGHT	25 g
COST	$24.11
USB	YES

The Arduino UNO specifications are compatible with our intended design. It also has features that will allow our device to be easily scalable which is a tertiary benefit of using a third-party MCU. These specifications will be compared to other microcontroller unit vendor options, before purchasing, so that we can optimize the microcontroller unit subcomponent.

Raspberry Pi Pico

Another very common MCU is the Raspberry Pi brand of MCU. The Raspberry Pi Pico is one of the newer versions of the Raspberry Pi family of MCU boards. The Raspberry Pi includes many features with a clock running at 133MHz, 2MB of on board memory, and built-in USB connection making it easy to connect to with existing wires and connection that we have. With 26 pins that are described as multifunction it has great flexibility with the design and can be soldered onto existing PCB designs.Also has great documentation with great external support of external devices. The biggest advantages of the Raspberry device are the programming language that the device supports being C/C++ and the large amount of features that the board inherently supports. The biggest disadvantage is the need to solder the board on after the board has been done and the Raspberry Pi Pico being more advanced means it is typically run non embedded so that it isn't typically soldered onto a PCB but is possible. Price wise the Raspberry Pi Pico is very reasonable at $4.00 before shipping and handling meaning buying multiple for potentially backup would not kill the wallets of the poor college student that has to buy them.

Figure 6.2: Raspberry Pi Pico



Like the Arduino UNO, the Raspberry Pi Pico microcontroller unit seems to be promising as well. It is, however, significantly cheaper than the Arduino UNO. To help compare to our other options, before making a selection, we listed the Raspberry Pi Pico specifications in the table below for quick referencing.

Table 6.2: Raspberry Pi Pico Specifications

MICROCONTROLLER	RP2040 microcontroller chip
PROCESSOR	Dual-core Arm Cortex-M0+
CLOCK SPEED	133 MHz
SRAM	264KB
FLASH MEMORY	2MB
MULTIFUNCTION PINS	26

ANALOGUE INPUTS	3
PROGRAMMABLE I/O	8
OPERATING VOLTAGE	3.3V
INPUT VOLTAGES(LIMIT)	1.8 - 5.5V
OPERATING TEMP.	-20°C to +85°C
WIDTH	21 mm
LENGTH	51 mm

MSP430FR6989

MSP430FR6989 is a MCU in the MSP430 family of board by Texas instrument. This MCU has 2 KB of on-board RAM, 2-bit ADC, comparator, DMA, UART/SPI/I2C, timer. It has features that include an on board timer, advanced sensor, and a scan interface. It runs from 3.6V down to 1.8V. The biggest advantages of the MSP430FR6989 is low-power and simplicity of the design. Running a low power MCU lets us have more flexibility in the design and if elected to make the device rechargeable we can make the device run for longer. When we say simplistic we don’t mean that in a negative manner it just means that the amount of things that the MCU can do is limited in comparison to other potential MCU for this project. However, for this project this MCU can accomplish what we need it to do. The biggest disadvantages that this MCU has is its limited capabilities, lack of built-in USB, and the software that we would need to program being less capable. The lack of built-in USB is simple enough to fix by soldering the lack of built-in USB onto our PCB but still important when factoring which to choose. The software that Texas Instrument uses for their boards lack as much documentation and potential code on the internet as more commonly used languages such as C/C++ and Python. This could make implementing our design more difficult than normal because we have to code in a language none of the members would be familiar with. While the language is still C it is done through a different device and has some interesting changes so that is still harder to implement than normal C.

Figure 6.3: Texas Instruments MSP430 Microcontroller

Further details provided in the table below by Texas Instruments:

Table 6.3: MSP430FR6989 Specifications

NON-VOLATILE MEMORY (KB)	128
RAM (KB)	2
ADC	12-bit SAR
GPIO PINS (#)	83
FEATURES	Advanced sensing, DMA, LCD, Real-time clock, Scan interface
UART	2
USB	No
NUMBER OF I2CS	2
SPI	4
COMPARATOR CHANNELS (#)	16

With these three MCU in mind we must compare and contrast their capabilities, cost and other factors to decide which one will be available and capable to be used in our design project. They will be compared in the table below in various different fields and criteria that we decided are most important.

Table 6.4: MCU Characteristic Comparison

MCU	Arduino UNO	Raspberry Pi Pico	MSP430FR6989
Spectrometer usage shown	Yes, however implementation is rarely seen	Yes	Yes, however technical communication is not as seen
Coding Language for Software	C/C++	C/C++	C
Embedded	No must be connected via wire	No must be connected via wire	Yes, able to be embedded into the PCB
Cost	$23.11	$4.00	$4.30
Availability	Yes	Yes	Yes, however running low on supply
Power Draw	5V	3.3V	3.3V

All the MCUs have advantages and disadvantages for our design. With this in mind the selection of MCU part is mostly about its capability the Arduino UNO board being high priced is most likely won't be selected because of the high price is mostly because of the advanced features and beginner friendless of the board however those aren't needed for this particular project so the price doesn't make sense. The next two being MSPFR6989 and Raspberry Pi Pico. For testing purposes it would be nice to get both so that we can see the advantages of both MCU in more practical purposes. The MSPFR6989 seems to be a better choice to satisfy the requirement for an Electrical Engineer to graduate with a harder implementation. The Raspberry Pi Pico seems overall easier and better priced however it may not meet the design requirements for Senior Design 1 in that its not an embedded MCU in a PCB and its being not embedded. The final selection will be the Raspberry Pi Pico. The main reason for this is that the Raspberry Pi Pico has shown to be accessible and easy to use and maintain a very competitive price. The major disadvantage that is seen in the need to solder the device indirectly to the PCB with wires and that this may affect the device is several ways such as portability and overall clean design as the MCU will be seen to be dangling by various wires to a the board instead of being actually on it. However, with these in mind the advantages of the MCU outweigh this as it lets us do what the device needs to do.

6.2 - Input Light Source

Our design and its capabilities will be entirely dependent on the light source that we end up utilizing. Three LEDs at three specific color wavelengths are utilized with the selected MCU. Blue light (grouped around 430 nm), green light (grouped around 505 nm), and red light (grouped around 660 nm) are used to address the absorption spectrum of chlorophyll, especially with reference to the a and b components of chlorophyll. This would enable the deduction of concentration of chlorophyll in distilled or drinking water.

LED660L, LED430L, LED505L
Above are the links to each LED which is being used.

The LEDs that are being used are listed below (THORLABS LED660L, LED430L, LED505L). These are used as the illumination source, and therefore are connected to the power supply. As mentioned previously, they emit light in the visible wavelength range. These LEDs are conveniently quite cheap compared to other light sources which could be used for spectrophotometry in drinking water, so that helps our budget considerations. One large consideration being put into the selection of three separate LEDs is the amount of power per nanometer of wavelength spectrum that we will get out of them. This is much better than if we had gone with a broadband light source, and it could have especially been an issue given possibly poor responsivity to lower ranges of visible light on the phototransistor.

Table 6.5: Input Light Source (LED) Specifications

Item #	Wavelength Range	Optical Power at 20 mA	Spectral FWHM	Viewing Half Angle	Max DC Forward Current	Package	Cost
LED660L	420 nm - 440 nm	8 mW	20 nm	22°	50 mA	TO-18	$12.41
LED430L	650nm - 670 nm	13 mW	14 nm	18°	75 mA	TO-18	$12.75
LED505L	500 nm - 510 nm	4 mW	30 nm	20°	30 mA	TO-18	$12.86

All of these devices meet the required specifications to be functional in our design. They are readily accessible, quite cheap in comparison to other options that are available, and are integrated into the electrical system that is included in the end-product. The specifications of the devices are also safely within the numbers to make sure the components do not break during testing, and they have specifications that do not conflict with each other when measurements or the like are made. For example, the LEDs are packaged in the same container with the same spherical glass lens, lending to our ability to use them almost interchangeably for the benefit of our design. These components are also used in our design demonstration.

6.3 - Directing and Focusing Input Light

Initially, there were plans for a system to direct specific wavelengths of a broadband input light source through the sample and then to the photodetector. The benefit to this would be a robust ability to choose any specific wavelength desired. However, the challenges and complications to this system were too much, and we chose to instead utilize three different LEDs in order to specify wavelength. Part of this decision was the consideration of optical power. The output optical power of a broadband white-light LED would be greatly reduced if it had to be split up into small sections of its output, such as less than tens of nanometers, to specify against the sample. This is also after the fact that only about half of the LED could even be utilized after collimation as well as considering optical noise or possible imperfections in focusing with the finalized system.

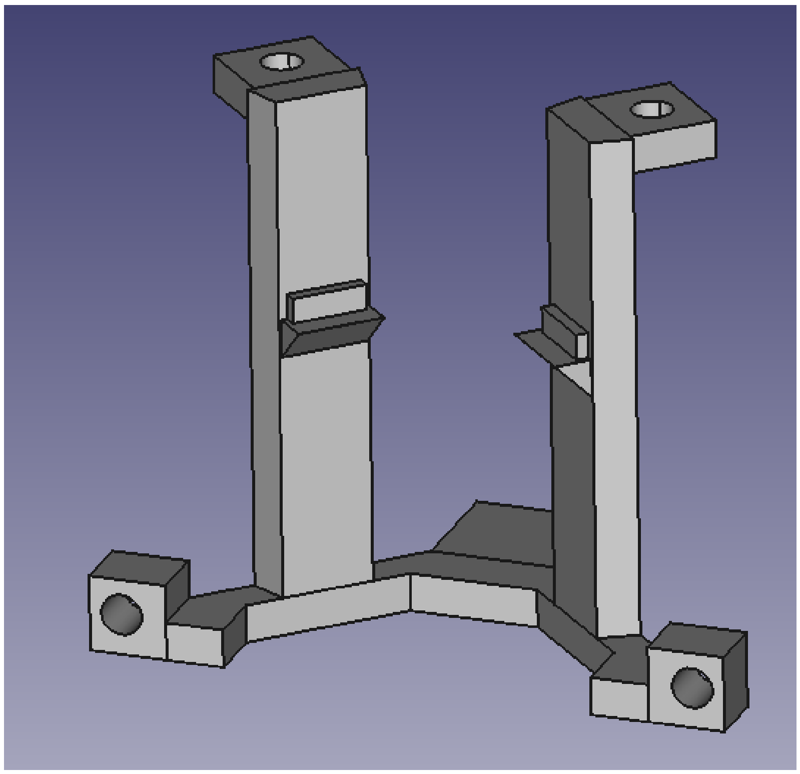
In the end, the group chose the 3 LEDs of single colors option, and a design was put together to place lenses and collimate the chosen LED. This system was put together in FreeCAD, making use of the free software that it provided, in order to print this at 3D printers that CREOL made available to Senior Design students. This option was chosen for its simplicity and straightforwardness in design (to combat the difficult extracurricular workloads of the 3-member team) and its ease/flexibility of acquisition, being that the 3D printers are a powerful resource for us. These printers allowed for flexible decisions on the design and tests of different iterations of said design.

One aspect of this system needs to be the collimation of the light involved in the system. In order to put light through a sample, the light ought to be collimated to ensure normal incidence to the sample. This will eliminate refraction differences that would then introduce unnecessary complications to the design. Additionally, the collimation would allow a known amount of interaction between the light and the sample, especially when taking into account the optical power distribution along the collimated light beam. Before, there were designs to introduce a diffraction element to split broadband light. This would cause there to be even less light to be selected through the system, and the collimated beam would have to be much smaller to allow for less blur when splitting light wavelengths, which would cause less light interaction with the sample. These complications were avoided, however.

Like mentioned earlier, the collimated light must pass through the sample. For this reason, we have chosen and are utilizing a circular jar to hold the sample, and this jar has as flat of a bottom to it as possible. The purpose of this jar is to allow light in through the top and have said light transmit through its glass bottom. The decision to make the light pass through from top to bottom was one made for many different reasons, but it is first important to note the amount of refraction that would occur if a circular jar allowed light in laterally. This would affect refraction and diffuse light away from the photodetector uncontrollably.

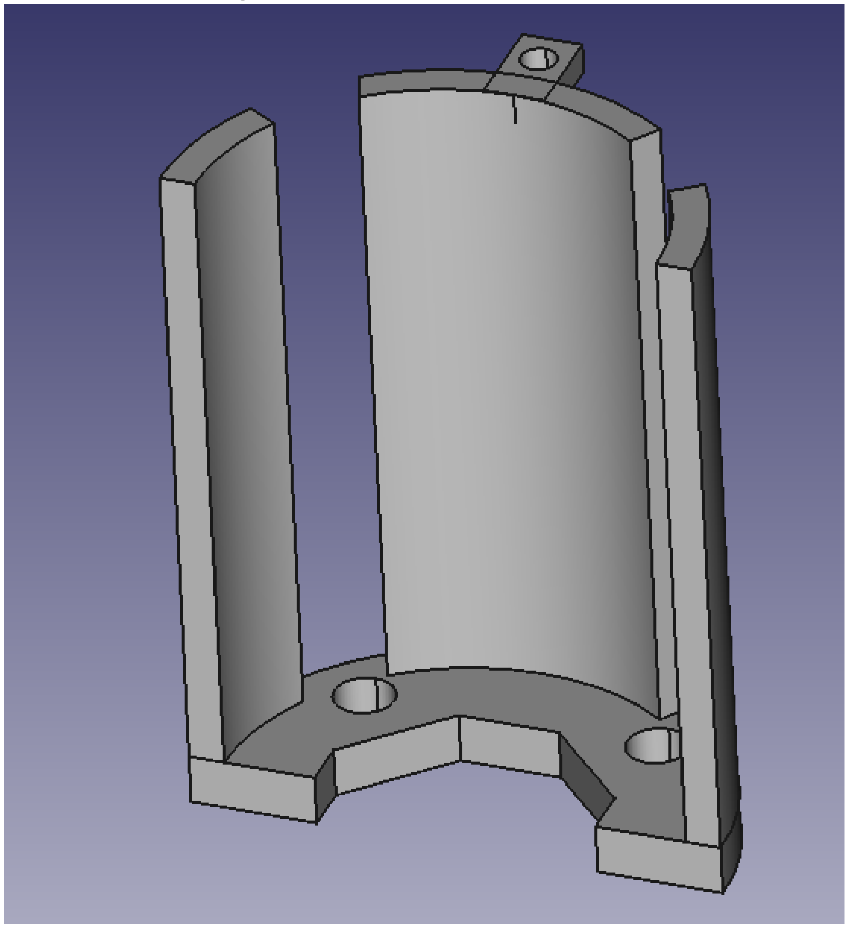
In the interest of having light pass through the system along a vertical axis, the chassis is designed to support itself from the bottom to the top, holding the lenses against gravity securely and minimizing the amount of movement of the optical axis with reference to the input light source and the photodetector. Images of the 3D design of the chassis are below.

Figure 6.4: Chassis Bottom Component



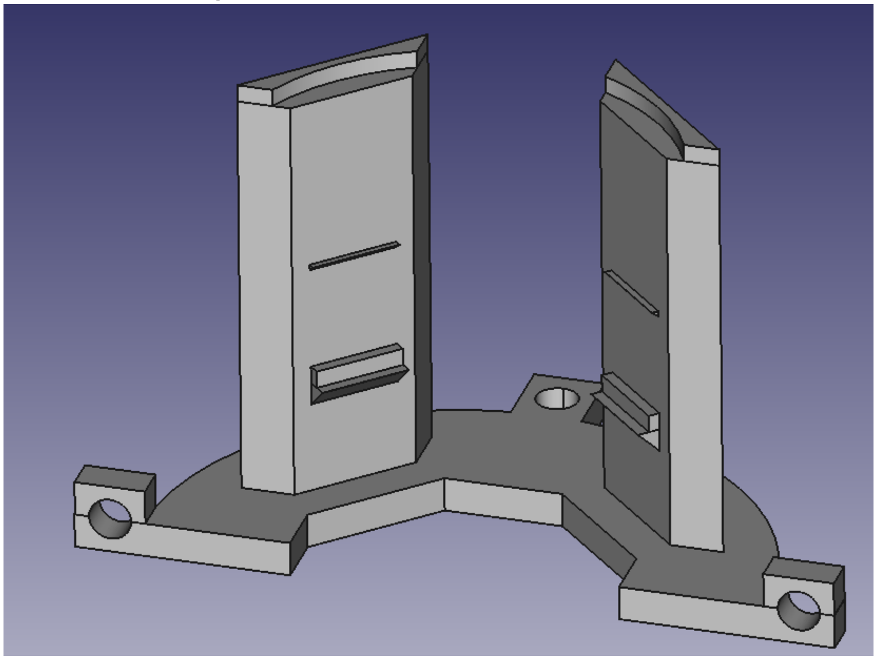
Above is the bottom component of the chassis. It is designed to hold the bottom-most lens with a tolerance (between the holder and the radius of the lens) of .08 millimeters. This is, of course, only half of the bottom component. The reason why these components are split in half are to increase ease of replacement if a piece is broken, as well as to allow for more versatility in its employment. If necessary, one component of the chassis can be taken half-off to address anything happening in the middle.

Figure 6.5: Chassis Jar Holder



This component is expressly designed to hold the jar securely while allowing light in from the top and bottom. It was carefully made to allow for small tolerances of the jar's fitting laterally, while also allowing it to connect to the other components, making sure it is secure while doing so. Any spilling of liquids would be catastrophic to the design, so it is secure from doing so. The half-component design was utilized to make the jar easy to remove and replace with this component, which does not have screw holes to connect to its half-partner, and instead has screw holes to connect above and below it.

Figure 6.6: Chassis Top Component



The top component is the busiest component, which has the most designs for small tolerances than other designs. It is designed to connect to the jar holder on bottom and the other half of itself laterally, on the base. Additionally, its walls have parts to secure into place the optical mask, the top (first) lens, and the LED, which shines down from the top, secured into place by a holder which fits into the circular outline at the top of the walls. Additionally, the walls have chamfered outcroppings to catch onto differently sized holders which maintain different components. The top is the optical mask, as mentioned before, and the larger chamfer is the holder designed for the lens. A separate mask for the lens was made and remade many times to make sure it held the lens very well and securely. The benefit to it being separate is it being able to be taken out and placed as desired, as well as it being able to be remade as testing continued on the design.

Our design, which is seen and described above, ultimately relies on the interchange of holders of LEDs. The mechanics of our project were such that we did not have the resources to make a windmill-style interchange, so this substitution was made. A mask for the LED's light to be selected at 20 degrees of its viewing angle was created to segment the input light before the first lens is found. The ultimate use of this chassis is to hold the components in line with the optical axis and not to address external light. The final product would include a full covering of the system, which would also house the electrical components of the system.

6.4 - Light Selection Module

The concept of using a diffraction object was sought after during our research into this project for quite a long time. It had been our intention of having a robust and more complicated system prior to us realizing that our team did not have the manpower or time available to us to utilize any of these objects. This will be further explained in our conclusion, however the decision to forgo the diffraction component of the optical system was made due to this administrative issue and the considerations of the component adding much in terms of destructive after-effects to what was meant to be effective system.

We looked into materials to select for specific frequencies in our research and laid out their costs and benefits. Electro-optic modulators or acousto-optic modulators, for example, select specific frequencies to transmit through the object. There were also gratings and prisms that showed up in research, which could be used in tandem with a pinhole or mask to calculate, through geometry, the allowed wavelength from said diffraction element.

The goal of this object, to keep in mind while selecting the best option, was to choose an ideal wavelength to input into the sample, while using a single white light LED, making the design robust and upgradeable. Conversely, it was also possible to put this module on the other side of the sample. By this, I mean that we could use it to analyze solely the output light of a white-LED input that has gone through a sample.

<u>Acousto-Optic Modulators</u>

Acousto-optic modulators are exciting items because they can, with extreme precision, select for a propagating frequency, as well as steer beams with powerfully accurate selectability. This functions off of the principle of the Bragg condition, where a specific angle and frequency of an input light beam interacts with a crystal, which has an acoustic wave propagating through it.

The numbers involved in the process are sensitive, which contributes to difficulty in developing such a component for this system, and the general price for acousto-optic modulators is unfeasible for this role. Additionally, as mentioned before, it is extremely sensitive to input and output light, and is ultimately not effective to select for variable frequencies without working with the modulator closely and with some expertise.

<u>Electro-Optic Modulators</u>

Electro-optic modulators are powerful tools to modify different aspects of a laser beam going through this module. By choosing the material carefully and running an electric field through a modulator, one can affect the refractive index of a material, among other optics-interactive properties. Through these principles, one can effectively modify phase, amplitude, or polarization of an input light beam. This, however, does not apply to the frequency selection important to us in this role. Even though a component like this could offer robust capabilities in manipulating the input light into the system, it would offer only minor conveniences to our objective. Lastly, it is important to mention, that due to the sensitivity of the intermediate components required to produce both acousto-optic and electro-optic modulators, these devices tend to be quite expensive, which puts them outside the realm of scope for our design.

Diffraction Gratings

Simple diffraction gratings, which are made up of many small slits in an opaque pane, offer powerful capabilities for understanding Near UV-VIS light. Diffraction gratings work off of the principle of interference and the wave nature of light. Due to the size of the slits (which can be changed) the incoming light responds by coming out the other side of the slit as a wave, as opposed to a ray. If the incoming light contains many different wavelengths, then the component wavelengths of this light will react to the slits differently.

The reaction depends on the relative size of the slit to the wavelength of light. Then, due to the distance between slits, the waves of the input light will interfere with each other at specific points in space in specific ways.

If one knows the distance to a detector array and the geometry of the diffraction grating, then one will be able to predict how the component wavelengths of light will interfere constructively versus destructively, allowing the observer to analyze the light for the intensities of each component wavelength. This tool is ultimately very robust and quite cheap for ruled gratings, as opposed to other types of gratings, which will be discussed shortly.

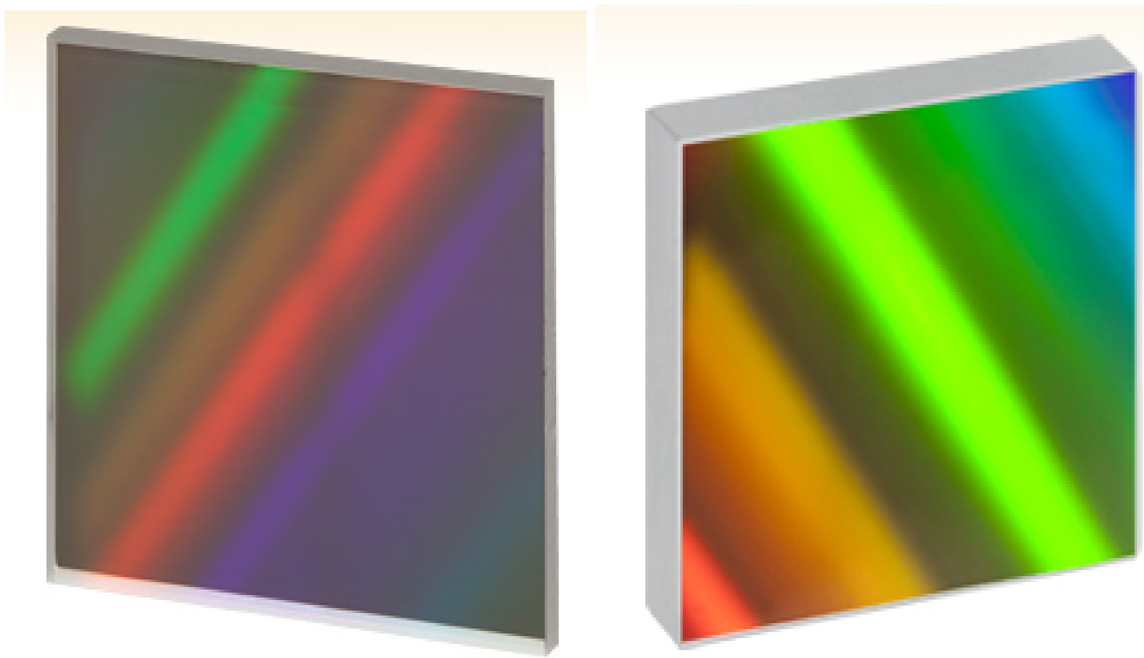
Different Types of Diffraction Gratings

There are different strategies, in optics, to diffract light using the principles listed above. The primary and most classical strategy is where one cuts lines into a small panel according to a desired slit width and spacing. This of course creates a “master grating,” from which replicas are made, and this provides no significant change in performance and allows for a low-cost grating to be made. This is the easiest method to produce diffraction gratings, with perhaps the lowest cost of any available kinds of gratings.

That being said, ruled gratings can present errors in fabrication and therefore use, which decreases the quality of any output or analysis of a source. Especially in a situation where the fluorescence, scattering, or absorption of a material must be closely monitored to see its concentration in a liquid medium (like our project), this could be a major downside in achieving a sensitive device, which could detect on the scale of parts-per-million.

A different, and more expensive strategy for manufacturing diffraction gratings is using interference lithography to manipulate refractive indexes in a material, creating a kind of diffraction grating called a “holographic diffraction grating.” In this grating, there are no errors caused by imperfections like in a ruled grating, as it is very precisely constructed without physical “grooves” or “slits.” Although this could decrease imperfections in the analysis of a light source, they are generally much more expensive to buy compared to ruled gratings.

Figure 6.7: Transmission Diffraction Grating (left) versus Reflective Diffraction Grating (Right), both Ruled



Liquid Crystal Diffraction Gratings

Liquid Crystal Diffraction Gratings offer a potential for a modifiable diffraction grating, which uses an applied voltage to “activate” its effect as a grating against an input source of light. It has been shown to have an effective diffraction of up to 12% on an He-Ne laser for first-order diffraction at a polarization that draws out the maximum diffraction. This use of the grating is, however, confined to lasers.

The light involved with the diffraction phenomenon within Liquid Crystals depends on polarization, which means it would be much less efficient in diffracting unpolarized, uncollimated light such as the light we plan to use as a light source, namely a white-light LED. Although it is tantalizing to be able to control the diffraction of a light source to produce a robust system of light analysation with a potentially cheap material and energy consumption as liquid crystals with applied voltage, it is unfeasible for the purposes of analyzing this light.

Dispersive Prisms

In order to isolate wavelengths, one needs a dispersive element to either diffract or refract light, both of which depend on wavelengths. Optical Prisms are glass prisms that have optically active surfaces that can either steer beams or disperse light sources into the different wavelengths that make up said light. They are popularly known to be able to disperse light, though their primary uses are steering beams or affecting image handedness and parity. There are many different kinds of prisms, with many shapes and corresponding uses, but the prisms that are useful to spectrometry are called "Dispersive Prisms," which obviously refers to their function.

The two main kinds of prisms used in light dispersion are Equilateral Prisms and Littrow Dispersion Prisms. These Equilateral Prisms are triangular, and are the kind of prism most would think of when dispersing white light into its individual chromatic elements, thanks to popular culture influences. They have three optically active surfaces, and two of those surfaces usually refract light to different degrees based on chromatic wavelength. Littrow Dispersion Prisms can also serve as dispersion prisms if they are manufactured without a coating, however they are primarily used for beam steering and other functions.

In terms of dispersion, these prisms function well, and won't cause aberrations that ruled gratings might be vulnerable to. They also have the benefit of classical use, so they are not difficult to work with, and there is plenty of information on their use in spectrometers. They are also generally not very expensive, however they will be quickly ruled against if they are compared with something very inexpensive, like a ruled grating, for the purposes of similar functionality as ruled gratings.

Fabry-Perot Filter

Fabry-Perot filters are filters that utilize the principle of constructive/destructive interference within a Fabry-Perot etalon. This is a relatively simple concept for Laser Engineers, where one would immediately recognize the cavity of this etalon as a classic laser cavity. One would then realize that this principle can be tuned to specific wavelengths based on equations relating to laser resonance and free spectral ranges to customize the frequency being allowed through the cavity.

This is, however, difficult to manage in a more unpredictable environment, and would take precision to modify the cavity length, orientation and angle, and therefore interference within the etalon. For use in a product, it would call for precise construction of a mechanism to keep it in place and allow it to be adjusted for use, which is out of our ability to manage.

Multiple Color LEDs

In the case of using multiple single-color LEDs, the complexity of the design goes down while increasing the effectiveness toward a single material. In our project, we have scaled down the effective use of the system to only include a single material, and so multiple single-color LEDs become possible to be used. A pro to this option is the higher reliability of power output into the optical system to then be measured on the far end, by the photodetector. Although an amplifier is used at the far end to make sure the photodetector can measure what it records, the resolution for the measurement still depends on the variation in power delivered to it, which can change much more based on a ratio of small power versus a better ratio of larger power.

Although there are drawbacks to this strategy, such as the lack of variety in the useful wavelengths, the benefits are important to our group in particular. Administratively, our group members, of which there are only three, have had many extracurricular commitments to do, and therefore a lower-complexity system, which has a proper effect, is desirable to something that can possibly fail to work or be effective.

Conclusion

Now that we have researched various frequency/wavelength dispersion mechanisms, we have provided a table below, listing the specifications of the light selection components considered.

We listed each option based on cost, frequency selection precision, and convenience to bring attention back to our initial project intentions. We prioritized first: low cost, precision, and convenience (in that order) to determine which component we wish to move forward with. See the chart below to view our component functional analysis breakdown. This chart was created using estimates of each component's practical points in each preferred characteristic. We used this matrix to help make a decision on what we decided to utilize to choose wavelengths.

Table 6.6: Light Selection Module Research Comparison

	Cost	**Frequency Selection**	**Difficulty to Work With**
Acousto-Optic Modulators	Very High	Very Precise	Very High
Electro-Optic Modulators	Very High	Ineffective	Moderate
Ruled Diffraction Gratings	Low	Precise	Low
Holographic and Reflective Diffraction Gratings	Low	Precise	Moderate
Liquid Crystal Diffraction Gratings	Unknown	Somewhat Imprecise	Very High
Optical Prism Gratings	Moderate	Precise	Low

Fabry-Perot Filter	Very High	Very Precise	Moderate
Multiple Different Color LEDs	Low	Precise	Low

Based on this conceptual comparison of researched dispersive elements and frequency selectors, the conclusion we reached was the multiple color LEDs. Like mentioned before, this option was desirable to our group due to our combined workloads and to what extent we could all coordinate a more complex system. One can find the LED specifications in the light input section, where it specifies the LED's capabilities. These capabilities are discussed elsewhere on how they can be effectively applied to our selected contaminant.

6.5 - Initial Optical Reception System

This section outlines a preliminary approach to our optical reception system. Our design changed from this initial consideration, which will be explained later. In the case that our design would have stayed along these lines, we would have had a reception system to direct our input light through multiple branches.

The spectrum of light exiting the diffraction module would be filtered and measured by utilizing the following outlined optical directory system. The diffraction component would be rotated on its rotation stage to select specific wavelengths of light for measurement by the device. An aperture with a 50/50 fiber split coupled onto the opposite end would have been at a stationary point within the optical axis. Depending on the angle of rotation of the diffraction module, specific wavelengths could be directed toward the aperture for transmission to the test and control sample (distilled water) through the fiber optic coupler.

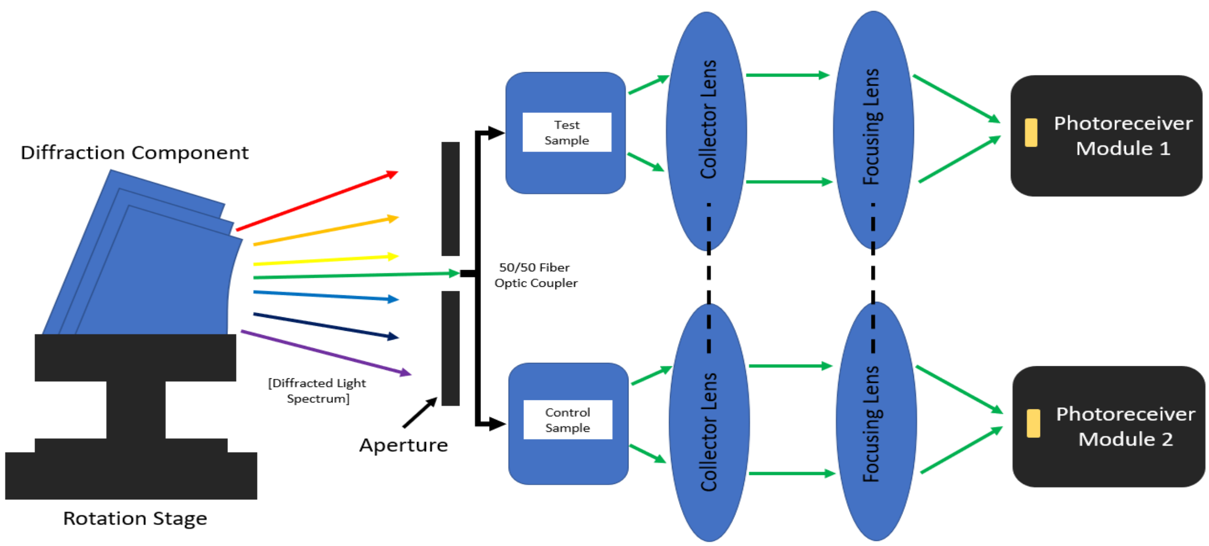
Each sample should have had relatively similar levels of input light intensity exiting the fiber. The intensity output of the light measured and calculated on the controlled sample side would be referenced against to account for any losses experienced by the container of the sample, which would be similar on both ends, or losses experienced by the water itself. The 'output' on the control sample side would essentially become the new 'input' for calculation related purposes. The samples would have clear surfaces perpendicular to the optical axis. The samples would also be 1.5cm in length, along the axis of propagation. This value would be used for calculating absorptivity by the Lambert-Beer law.

Upon exiting the sample, all transmitted light would enter a collector lens, to collimate the light once again, which would be paired with a focusing objective lens a set distance away. The focusing lens would focus all transmitted light onto a phototransistor where the total intensity of the output light could then be calculated, using optoelectronic equations, with respect to the changes in current the phototransistor induces.

The components of this optical directory system and the transmitting end of the system would all be selected with the intention to minimize the overall cost and space required by the system to operate. Any simplifications to the design in terms of joint-purposes of complex lenses as substitutes would be taken advantage of in the build process. All geometric data required for determining specific lens focal lengths, distances, and sizes would also be determined as availability of products are investigated.

This section included data that is both independently and dependently gained, and due to the use of commercially available equipment that is generally less expensive and accurate, we could expect to have a margin of error in our software generated calculations that causes our ‘selected’ wavelength to have been off by a few nanometers. This is not an issue; as opposed to sampling wavelengths by the individual resolution, we could still make due with a wavelength sampling resolution of 10-20 nm as it would still allow us to develop a fairly accurate impression of an impurity absorption and transmission spectrum.

Figure 6.8: Potential Optical Reception System



To efficiently direct the dispersed light in a fashion that allows us to select specific wavelengths along the dispersive spectral axis, we could have utilized a fiber optic device, Dual Branch Light Guide from Edmund Optics, that would couple imminent light towards a test and control sample. This would eliminate the impact of wavelength specific intensity variations due to the input light source, light cohesiveness, or the influence of optics on the intensity distribution.

Since absorption could be measured as the ratio of light transmitted through a substance vs. the amount transmitted assuming the substance is absent, using a fiber to equalize our input intensities into both the control and test sample would prove to be highly convenient. Fiber optics light guides are also flexible, allowing us to position the coupling end along any plane, in parallel with the ideal diffraction spectra screen. The specifications of of our selected light guide are as follows:

Table 6.7: Fiber Light Guide Specifications

Item	Wavelength Range	Numerical Aperture	Core Index of Refraction	Cladding Index of Refraction	Loss	Dimensions	Cost
Dual Branch Light Guide	400 - 2 µm	0.55	1.581	1.487	6% per 12” at 600nm	¼” by 36” 50µm Diameter	$148.00

In conclusion for this section, we decided against this design choice because of its complexity in implementation for spectral resolution and its threat of cutting away too much power. If too much power is cut away from the system, then measurements cannot be taken properly and the system has a catastrophic miscalculation which would require its full redesign.

6.6 - Photodetector

The photoreceiver is extremely important in a spectrometer for its ability to resolve different incoming intensities of light per each pixel of said device. This could be an array of pixels, or it could theoretically be a single pixel that is iterated over a distance.

The point is to gather linear data on incoming light and its intensities at each point in order to calculate the intensity corresponding with each wavelength. This can either be calculatable based on known distance to the diffraction grating and a known angle to each pixel into which the light is entering, or it can be learned from color sensors and careful understanding of how said color sensors work. Either strategy presents its risks and both require understanding of how the light is being measured.

There are example responses per a spectral input where CCD arrays can use multiple color-focused detectors and overlap their photonic sensitivity, and it is therefore seen that the regular sensor is more sensitive than the color sensor by definition. Not only this, but if we used a color sensor, we would have to do more complicated calculations to determine the spectral response of our output light than just finding the angle of diffraction and intensity based on the expected response.

There are different kinds of cameras and imaging array sensors that can be chosen from, which will influence our dealings with these calculations along with other considerations. Two main imaging array strategies are CCD and CMOS sensor arrays, and other more basic phototransistors open to us as options.

CCD Sensors

CCD (Charge Couple Device) sensors have been more popular in the past, but have started to be phased out due to advancements in other sensor technologies. The principle of CCD starts with phototransistors.

Photodiodes work by having a photonically sensitive semiconductor. A semiconductor, with a P and N material on either side of a junction, simply called a “P-N Junction,” essentially produces an excess and a lack of electrons on either side of a divide. This causes a potential difference in the junction. The condition for photosensitivity is achieved with careful construction of the semiconductor to have a particular gap between the two materials.

The energy gap that stops the excess of electrons on one side from recombining across the gap with receptive holes can be specified to be along the energy of a photon. Incoming photons can provide the necessary energy for an electron to cross the gap, and this (if connected with a proper circuit) can cause a current to begin to flow through the transistor. The measurement of this current can allow a corresponding measurement of the incoming light and its intensity.

CCD cameras are constructed by taking electrodes, which function like these phototransistors, and store charges from a set amount of exposure to an input source of light. There are horizontal arrays of these electrodes that store energy from this light, which, after the exposure period, will begin to “read out” to a carrier of sorts. This carrier brings each of these sets of stored charges to where they can be understood and eventually turned into an image. This strategy of detection provides the capability of global shutter, which means every pixel can be exposed at the same time and produce a comprehensible image.

CMOS Sensors

Opposite to CCD cameras, CMOS (Complementary Metal-Oxide Semiconductor) sensors were not used as popularly in the past, but have recently become more inexpensive and more powerful than CCD cameras. CMOS cameras used to only be able to expose lines of its sensors at a time in order to obtain a comprehensive image, which is called rolling shutter. Now, due to advances in the capabilities of this technique, CMOS obtains global-shutter effects with lower noise, no smear, and higher frame rates as compared to CCD.

The principle of CMOS cameras is more robust than the CCD in that, as opposed to CCD cameras where the voltage from the received light is converted away from the pixel where it was received, the CMOS converts the voltage from the received light at each pixel, where said information is then taken in and analyzed on a row by row and column by column.

Phototransistor

Phototransistors have been discussed before. They have a heterojunction design to amplify the current caused by the recombination in the active region of the semiconductor. These are effective tools for measuring light by outputting a current. As we will see later in the paper, they can be coupled with an amplifier to have a voltage measurement become both possible and desirable.

These are also very small and affordable. If we are looking to focus light onto a point and measure its intensity, this will be ideal for us to utilize.

Conclusion

The group went with using a phototransistor. Due to the objective of the project being to measure the absorption of a substance, we only need to worry about measuring optical intensity on a single point. This means that, economically, only using a single photosensitive semiconductor such as a phototransistor can accomplish our objective simply and economically. Especially given that the phototransistor had a more sensitive response to incoming light than photodiodes, we should use these to capture light and be able to measure its intensity. The phototransistor we went for and its specifications are shown below.

Table 6.8: Phototransistor Specifications

Item #	Wavelength Range	Spectral FWHM	Viewing Half Angle	Max DC Collector Current	Package	Cost
BPW77NA	450 - 1080 nm	N/A	10°	50 mA	TO-18	$13.00

6.7 - Power Supply

Power is the one of the core components of any modern device as without it no electronic device will be able to work. This is more prominent in modern day as the reliance on electricity is becoming more prevalent as its efficacy and ways to be used are increased. For our device to work it must be powered so that the multiple components of it can work suchs as the MCU, light diodes and other optical components. The key aspect of the power supply is being able to power all aspects of the device at the same time and not have the device either explode or turn off due to lack of power. For this power supply to work we must know all the aspects of the device that need power and how much.

Power sources are the source for the device to get its electrical energy from and this can many times determine the other aspects of the device. The first stage of creating a power supply or power system is determining how and what is gonna actually be powering the device. There are various ways that we can be expected to power a device such as battery powered, solar powered or just straight plugged into the wall powered. Each is used for various forms and each offers various forms of advantages and disadvantages. These forms of power generation will be explored and then compared and contrasted in the next following paragraphs and.or pages of this report.

Battery Powered

When we describe a system as being battery powered we mean in the aspect of using external sources of power in typically the form of alkaline batteries and/or lithium-ion batteries are the actual sources of the voltage and current of the device. Alkaline batteries or lithium-ion often come in various sizes being AA, AAA and even large sizes that are rarer such as D or C. The sizes don't do anything for power draw or battery life so for this discussion we are gonna go with the AA batteries that are made with Alkaline to make things easier for discussion. AA batteries are chosen as they are extremely common and used for most consumer products.

The advantages of being battery powered is simplicity, portability, and feasibility. Being battery powered is very easy to make a device as we just need to design a chassis to hold the batteries and connect it to PCB and it is easy to understand for a non scientific minded person as they just connect the batteries and then the device magically works. The device becomes portable with battery powered in that as long as the device has juice in the batteries the device can be powered. The feasibility becomes easier as with having a well-known and tested source means that we have a greater flexibility.

The biggest disadvantages with being battery powered is limited scope and less power draw. With batteries the scope of what we can do becomes more limited as the power draw becomes much less constituents. As batteries become used more and more than actually can lose their ability to provide the necessary current and this can stop the device from working. Overall batteries are a time tested method however their simplicity in execution makes their scope limited.

Solar Powered

Solar Power is using the power of the Sun to generate electricity. The most common way that this is done is with the use of solar panels or solar cells. Solar panels are typically blue-green squares that when hit with photons cause the electrons in the solar cells to move creating electricity. Solar power has become a common way for devices to be upgraded and become 'green'. Green means clean energy in this case. Solar powering the device will entail the use of a small solar panel embedded into the device.
Solar panels can generate a wide range of power depending on the size of panel we decide to use. If the device were going to be solar powered we would have to buy a solar cell of appropriate size and then connect it to the PCB.

The advantages of using solar power are environmental effects, challenge and interest. Using solar power would give the device environmental reasons to differentiate on the market and help with using the angle that the device is better for the environment. Solar power is something that only the members have researched so it will be a great learning opportunity for the members especially in the area of renewable energy to practice and get some experience in. Interest in green energy and specifically solar power has been on the steady rise for some decades especially as news about global climate change and its harsh effects are becoming more and more apparent. This again lets our device stand out in the open market giving it better appeal.

Solar power has some huge disadvantages, though, with the most noteworthy ones being feasibility of it. Solar power relies on the Sun being visible in the sky and clear of any abstractions to generate electricity. This is a problem for if you wanna use the device inside or at night as while some indoor lights can generate the necessary lumens to generate electricity with a solar cell at that point why not just plug it in to a wall. Solar panels are also less reliable and efficient making it necessary to buy a larger amount of material for the same benefit as other power sources.

Wall Outlet

Wall outlets in the United States are standardized with 120V and 15A. This is much more than any typical household appliance can handle so most devices use either some form of step down converter to lower the power coming in or adapters. The device being powered by a plug in will 100 percent require the use of these options as the use of these power levels will either make the device catch on fire or explode and that is not cognizant of our design. A wall outlet for the device will most likely be connected to some sort of adapter that will be built of step down voltage regulator and other circuits that will narrow down the value of the voltage and current to more reasonable levels of 5V and 2.5A respectively.

The advantages of this power source can be seen in feasibility, simplicity and straightforwardness. The feasibility for making it work is extremely easy as the hardest thing that would have to be done is creating an adapter for converting the wall outlet power to appropriate power values which would only the creation of the voltage regulator to oversimplify the matter. The simplicity would help in both the design and user process as with the ability to just plug in the device and have it work so that it makes the user just understand how it works.

The disadvantages of this process is the lack of portability. A major problem of wall outlets is that they are only available in specific locations typically in or near buildings and if the device needs a wall outlet it cannot really be called portable if it needs to be constantly next to one to work. Overall the large disadvantage of lacking portability means that Wall Outlets may already be a lost cause.

All the power sources have advantages and disadvantages inherent to their design however some are much more feasible than others. There is also a way to combine the aspects of both power sources of battery and wall outlet by creating a lithium ion battery and making the device rechargeable.

Rechargeable

Creating a rechargeable power source is a combination of two previous power sources that we mentioned before those being battery powered and wall outlets. Rechargeable is used very similarly to battery powered except in two major aspects: the user will not need to change the batteries for a significant amount of time and the battery is not an external part of the device. Rechargeable batteries come in various different types such as lithium-ion and nickel-cadmium. The difference will be explained in future paragraphs later on in the report.

The rechargeable power source will be implemented with various electrical components that will both have to be purchased and designed. The battery that will have to be purchased as the creation of a lithium-ion or nickel-cadmium is way beyond the scope of two semesters and is very dangerous even for experienced chemical or electrical engineers. More important to the power supply will be the creation of the charging circuit. The charging circuit will be important as it will be how the device charges the battery so that even if it drops to zero charge the user will just have to plug it in to a local exterior power source.

The advantages of using rechargeable power sources are portability ,simplicity to the end user, and challenge. With a battery that can be made to last and has the ability to be taken anywhere as long as the user makes sure it doesn't run out, portability of the device will be on par with just using normal batteries. This also will be simple to the user as most modern users are very familiar with the idea of charging items such as phones as such. Creating a rechargeable battery has many unique challenges to any budding electrical engineer, especially one who has only done research and had no hands on experience making one.

However the rechargeable power source has some noteworthy features such as inherent costs of more electrical components, battery life, and need to watch power draw even more. The biggest up front cost that will be needed are the need to buy a battery that can be charged, however these should be readily available in various forms and sizes. Battery life is going to be a factor the device must be able to do its prime objectives and still have some juice left so that it can do it multiple times meaning that extra care and calculator will be needed to make sure the battery lasts long enough for it to be worth it. The time scale we will look at should be a couple of hours of continuous use as the actual device shouldnt take forever to calculate the water impurity.

Furthermore, the power draw must be watched extra carefully as it affects a large portion of the battery life and become much more notable to the consumer even if they are not especially scientific literature or minded.

With the selections that were given in the preceding number of paragraphs the power source for the project will be a rechargeable battery that will be connected to the PCB. The battery’s chemical compound and nature will be explored in following paragraphs in aspects such as chemical compound, size and location in the device as all are important to the logistics of the device.

We outlined the advantages and disadvantages of each Power Source to aid in determining which would best apply to the design. They have been provided in a chart for quick and easy reference. The comparison can be seen in the table seen below:

Table 6.9: Power Supply Advantages and Disadvantages

Power Source	Advantages	Disadvantages
Battery	• Portable • Easy to use • Easy to understand for the user • Feasible to design	• Battery run out • Limited scope • Could be seen as too simple for design
Solar	• Intesting, • Challenging the designers • New idea for the market • Renewable energy • Portable • Outside capable	• Not feasible • Less efficient for price • more expensive • Cannot be used at night or during inclement weather
Wall Outlet	• Feasible to design • Known to design so plenty of info • Straight forwardness	• Not portable • Need for converting power from AC to DC • Need for voltage regulator from 120V to 5V
Rechargeable	**• Portable** **• Easy for end user to understand** **• Easy to design but still challenging** **• Feasible to design** **• Potential to have longer life than Battery** **• No need to change battery after they run out**	**• Battery life** **• Need to design charging circuit** **• Need specific battery that can be recharged** **• Flammability increases** **• More expensive compared to Battery** **• More components.**

Conclusion

With the above information available the power supply for this device will be one that is rechargeable that is for the many advantages that this will allow for the device. As portability is an important aspect of this device a rechargeable battery will allow the end user to be able to carry the device around where they would like. Another advantage is the familiarity of the device's power supply to a large of our potential customer base. Rechargeable devices are incredibly common in today's society so many non-tech savvy users will be able to understand the need to plug in and charge the device.

It will also be challenging as the need for a charging circuit is needed. Most power supplies get continuous power so they do not need to be constantly charged. However, in a rechargeable power supply the need for one is pretty self explanatory. The creation of one will be a new avenue for our members but are more than welcome to the task. The biggest disadvantages are the price and challenge to have a device be rechargeable. Having to create a charging circuit will require more components and in turn cost more to produce in the end resulting product. With all that in mind overall the rechargeable is the best for our product/device while providing enough challenge for a graduating Electrical Engineer student.

6.8 - Battery Chemical Compound

The battery is one of the most important aspects of the design as the device's power source is one that has the ability to be recharged. The battery must have the ability to be recharged, last long enough for the user to use the device for multiple uses over a long enough time, and fit within the dimensions of the device. For rechargeable batteries the chemical composition is very important as the ability to recharge batteries is not inherent to every type of battery making compound. The main difference between a rechargeable and a non rechargeable battery is that a rechargeable battery when a current goes through can be reversed, this also lets it be rechargeable.

For rechargeable batteries there are three main compounds that use these are: Lithium-Ion, Nickel-Metal Hydride, and Nickel-Cadmium.

Out of these three compounds Lithium-Ion further written as LiOn is by far the most common of the three and is typically the most modern of the chemical compounds.
Nickel-Cadmium was one of the older rechargeable battery that were used however had many problems one notable problem was one with memory with the battery if it wasn't fully discharged it would lose its capacity making the batteries much less efficient and had to be replaced a lot more of the time which a negative effect on the consumers. Nickel-Cadmium batteries are more common however they are older than the Lithium-Ion batteries.

Nickel-Cadmium are bigger and heavier than other rechargeable batteries and because of this they tend don't to not be used in bigger capacity in devices such as electric cars or similar large devices. However, the best advantage of Nickel-Cadmium is that they are cheaper than the alternative batteries such as Lithium-Ion and Nickel-Cadmium are also more durable than Lithium-Ion in more extreme temperatures.

The third compound is Nickel-Metal Hydride which was used for high current devices. Unlike the prior two choices, Nickel-Metal Hydride is environment friendly. Unfortunately, the memory effect that persisted within this compound caused it to go out of use for batteries in the early 21st century.

To better illustrate the varying compounds utilized for batteries, we put together a chart for quick reference. The table below will aid in visualizing the comparisons of the battery chemical compounds.

Table 6.10: Battery Chemical Compounds Contrasts

Battery Chemical Compound	**Pro**	**Cons**
Lithium-Ion	**● Most common ● Very little memory effect ● Charges fast and discharges fast ● Highest Energy Density**	**● Most price wise ● Potential flammable if used improbable**
Nickel-Cadmium	● Cheaper ● Little memory effect ● Common in other consumer appliances	● Heavy ● Large ● Fading out ● Lowest Energy Density of three
Nickel-Metal Hydride	● Used for high current drain appliances ● Cheaper ● Environment friendly	● Energy Density still lower than Lithium ● Memory effect prevalent fazed them out for most part in the early 2000s

With the table above in mind the group has selected to go with Lithium-Ion for the battery's chemical compound. The main reason for this is the availability of getting a Lithium-Ion battery making it the easiest to obtain in a timely fashion. Another large reason is the use of Lithium-Ion in the industry has provided us with a large amount of documentation for its use so we can use the knowledge that others had made for our project. The main downside being price and flammability are fairly easy to deal with proper planning. Price is something we adjust for as well as the flammability of the battery will be handled properly by the members so that no one or the device gets hurt before end users get it.

6.9 - Display

The display is one of the most recognizable parts of a device to a non tech-savvy person as it is typically the first and only thing that many of them will interact with. This is why it is important to select a display that is clear enough for the user to be able to interact with as well as meet the technical specification for the device. For the device the display just needs to be able to display the information about the water sample that is provided from the device. This is the bare minimum that the display will have to do anything less than means the display will not be usable to complete the objective of the device and project. Displays have various forms such as LCD and LED and have various capabilities. In this section, we compared and contrasted the characteristics of three separate display typers for selection and integration into our end product of our final design. Preference was placed on devices that are cheap and relatively simple to utilize for our final design

LCD

Liquid Crystal Display is a type of display that utilizes tiny liquid crystals to display an image. Light passes through the liquid crystal to both colorize the image and display the image with fluorescent light. LCDs are very common in today's technological environment meaning that many users will be familiar with how it will work and not be surprised or shocked in its inclusion in a common device.

LED

LED displays get their name from the use of light emitting diodes that are at the back of the display to actually display the image to the user. LED displays still function similarly to LCD with light however instead of light coming from a fluorescent light it comes from the light emitting diodes. This leads to a better picture quality overall and more control over specific colors and light levels as the LEDs don't cause a bloom effect that LCD devices can suffer from. With the ability to shut off individual LEDs in the back of the display device it also leads to an efficient display power wise which can be important in selecting the three devices.

Analogous LED Display

Lastly, we have considered the possibility of creating a simple analogous LED display. This display will be highly limited in its ability to present data, but there are methods we can employ to ensure that the necessary data required is provided. An analogous LED display will be composed of separate pairs of single LEDs. For example, a single LED can be the display for showcasing whether or not the device is on or off in a simple switch fashion. For more detailed data, like the detection of certain impurities, we can have a single LED for each of the four impurities outlined in the device above. The impurity itself will be labeled on the chassis of the design. If Chromium (III) is detected, then its respective LED will be pinged on while the others remain off. The concentration can be depicted on a vertical row of LEDs. A scale can be labeled in adjudication to the LEDs, so that the more that are on, the higher the concentration depicted.

This design will be simple to program, and cheap to produce, but it will result in a very limited method of depicting information. All of the previous display methods each have their respective pros and cons. For quick referencing we created the chart below where the main pros and cons of the three different display devices can be tallied to aid in our decision making and module optimization.

Display Device	**Pros**	**Cons**
LCD	• Cheaper • On small size resolution doesn't matter as much • Powers from a single source • Simplicity	• Not as powerful • Resolution suffers • Bloom effect that affects quality
LED	• Better resolution • Better color • Smaller in thickness of the display • Less power drawn from the batter	• More complicated • Pricer • For smaller devices the resolution won't matter as much
Analogous LED Display	• Cheapest • Easy to program • Easy to troubleshoot	• Very limited in ability to display complex information • Requires extra Boolean circuitry

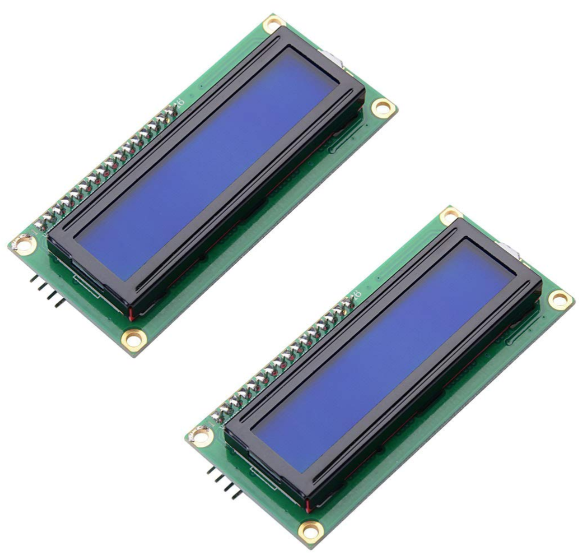
With the table listing the pros and cons of the display devices in mind, the one for this project will be a LCD display. The main reason is the display needs to be simple. The display will be extremely basic because it will only display very simple numbers and sentences because of this availability and cheapness are paramount. LCD is the best for this, the main advantages for the LED are only seen in bigger displays and more sophisticated displays both are not needed for the device.

The specific display that we will be using is the HD44780 IIC I2C1602 LCD Display. Despites its overall complicated and convoluted name it does exactly what we need for the display device. The technical specs are in the table below.

Table 6.11: LCD Display Specifications

HD44780 IIC I2C1602 LCD Display	**Description**
Manufacturer	Hitachi
Voltage	2.7V - 5.8V
Backlight	LED - Yellow/Green
Text Color	White
Background Color	Blue
Number of Characters	32
Display Format	16 x 2
Price	$11 for 2
Size L x W x H	80.00mm x 36.00mm x 13.20mm (3.15in x 1.42in x 0.52in)

Figure 6.9: Hitachi LCD Display



6.10 - Power Connectors

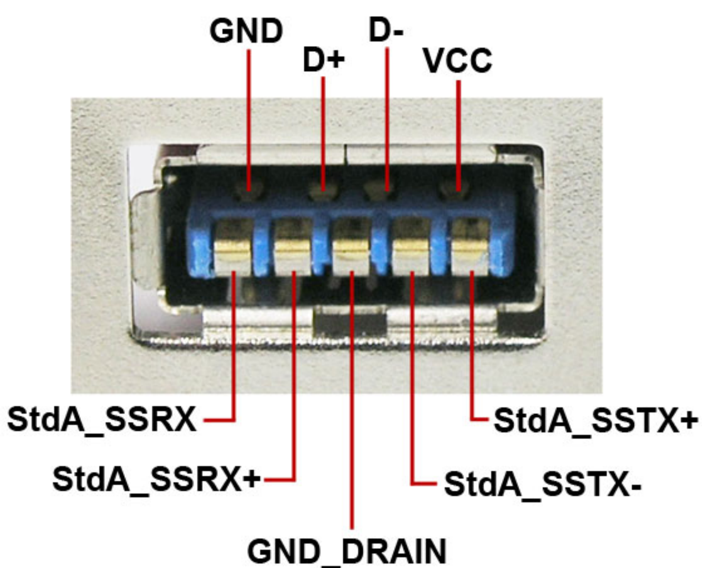
A major aspect in power design is the simple need to connect the power to the actual device so that it can be powered. This is where the importance of power connectors comes into play. Various different types of power connectors exist with very different technical specifications. However the most important aspect of them is how much power they can draw and where that power can be used.

For the purpose of this device and this project we used a USB connection to power the device and a more technical explanation of how that will be done look at the following paragraphs for the reasons that it was chosen. As a whole, a micro-USB, USB adapter wall plug, and AC to DC adapter will be investigated for implementation into the final product.

USB

Initially the device will be powered via Micro USB or the more common USB type B. Micro USB is a very common and used connection that many devices use making it extremely easy to find resources and use existing cables from other devices both making the project more feasible and cheaper to implement and produce if successful . MicroUSB lets us have 5V power draw like all USB cables meaning that device should not have a component draw more than 5V. The proposed MCUs for the device will not be using more than 5V so that is fine and even with their potential power draw being higher however we can run on low power mode as the MCU shouldn't have to do any advanced analysis using a ton of processor power.

Figure 6.10 USB pinout diagram



USB has a very simplistic and easy to read pinout diagram shown above and is one of the main reasons that they are used all over the world in all skill levels. The 4 pins represent the Vcc being the voltage supplied i.e. the power, the GND the ground wire that are used throughout all electronics systems, and the two D+ and D- which are used for Data transfer for specific applications. In this device the USB will be used mainly for power not data transfer so the main pins to worry about are the VCC and GND however connections will most likely be used for the data pins as well as to make sure not to short circuit the device with an open port.

Micro USB was chosen over the forms of USB because of convenience as all USB types are both readily available and cheap. The Micro USB will have to be soldered onto the final PCB so that we can connect to a USB adapter that can be plugged into an outlet to draw the power. USB is also a connection already built into one of the MCUs that we have determined for practical use on the project that being the Raspberry Pi Pico and the LED light that will be used in part for the optical design will also use a type of USB, albeit a different type most likely.

USB Adapter Wall Plug

USB cables have a typical power draw of 5V however that power must come somewhere and typically that is done with a wall plug and the adapter. The power that is following through a common American Household is 120V at 15A. This much power is way too much for most consumer devices so most devices come with adapters to convert that power to a much more convenient power draw.

The adapter also does an important job of converting from AC to DC power for a large amount of devices. Most devices don't need that large amount of power and even if they wanted it, it would most likely make the device that they are using explode with way too much current running through it. A USB adapter plug would be able to do this for our device and will be much more convenient to the end user than a typical power system. This is because wall plugs are pretty readily available making the device be able to be used anywhere.

AC to DC Adapter

Alternating Current is what the power grid uses to get power from generators and transformers into people's homes. However most home appliances and devices cannot use AC power so they must convert that AC power into usable Direct Current power or DC power. The way that most devices do this is by the use of an AC to DC adapter. An AC to DC adapter works with the use of transformers that transform the AC to unregulated DC power that your device can actually use. This goes down through various forms of converters such as forward or flyback converters that can use the input filtering to smooth out the power source so that device has a much smoother and then consistent power source to use.

6.11 - Lens Selection

In order to direct our light through our optical axis and our optical system, we needed to direct our light with accuracy and intentionality. If we do not collimate our light, for example, the way it will move through an expected volume of our sample will be difficult to determine. Effort will be made to keep the light we use on the optical axis, and for most of the system, the light merely needs to be collimated. For these reasons, the lenses to be chosen will be few and not very complicated. The only focus we might have is a focal length to be chosen, and how to choose the lenses given a desired size of device.

A final consideration for choosing lenses should be other aberrations that are possible with light, such as chromatic aberrations and other third order aberrations. Astigmatism, coma, and spherical aberrations should not pose an issue, as the light will primarily be collimated, and we are not attempting to find a diffraction-limited focal accuracy. Chromatic aberrations will also not pose too many issues since we tend to utilize largely uniform light sources in terms of wavelength. Since each LED still illuminates within a 30-40 nm wavelength range, consideration was still given to the cost-benefit of including an achromatic lens.

Achromatic Lens

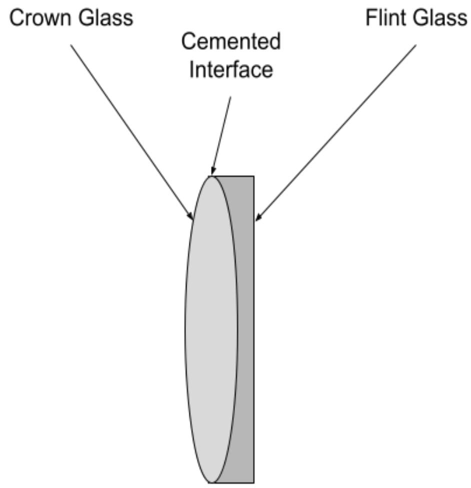
Achromatic lenses are lenses that are not as simple as the standard bi-convex lens that one usually thinks of when thinking of lenses. An achromat, as it were, is a combination of two lenses, usually cemented together. The objective, with two glasses cemented together, is to cancel out their respective chromatic aberration, which can be designed.

Depending on the properties of the glass on either side of this “achromat,” the chromatic aberration will be higher on one side and lower or opposite on the other, especially depending on the face that the interface in between the two glasses provides an opposite curvature, and therefore potentially provides an opposite effect. A visualization of this lens follows.

In the following figure, the crown glass is shown as the glass the light first enters through, as the optical axis travels from left to right. The light would then move through the flint glass, which would decrease aberration. The interface being “cemented” means that there is no air space in between the two glass materials, meaning that in an optical analysis, the interface through which the light would pass would be defined by only those two indexes of refraction, and it would not involve light.

Air-spaced achromatic lenses exist, but are difficult to manufacture, and are slightly less popular than cemented lenses. Achromatic triplets also exist, however are more expensive, and are more precise than our project requires from this part of the system. This happens because there is more to design. With three pieces of glass, there is more variability and control to the chromatic aberration per each piece. See below the figure below for a component breakdown of an achromatic doublet lens.

Figure 6.11: Achromatic Doublet Visualization



The meaning of “Crown Glass" and “Flint Glass” refers to the general categorizations that component glasses of an achromatic lens can be placed into based on their Abbe number, and more generally their refractive index. An Abbe number is calculated from the degree of refraction of light that exists at a standardized three different wavelengths, which provides a more holistic effect on visible light that a glass has.

Crown glass generally has a lower refractive index, and more specifically has an Abbe number larger than 55. This effectively refers to a lower chromatic aberration rate. Flint glass is opposite to Crown glass, with Abbe numbers below 50 and higher refractive indexes, generally. With consideration being given to specific glasses on either ends, one can very precisely design to minimize chromatic aberration for any situation one might need to.

Bi-Convex Lens

A bi-convex lens was perhaps one of the easiest lens to work with due to its simple and symmetrical nature. It is a lens that has a single glass material and two convex-curved surfaces. It works to converge light along an optical axis, which can work well as a collimating lens, though it could work well in other roles. Obviously, for our purposes, it will work as a collimating lens. This will produce much more chromatic and third order aberrations than the achromatic lens or other, more complex or specifically designed lenses, but it could work as a cheap and versatile unit in our lens system for directing optical intensity.

There are also educational biconvex lenses. These are no doubt very low in quality, with many aberrations and imperfections. The are, however, more than significantly cheaper than lenses that one could buy from a more trusted source like Thorlabs or Newport (lower than 15% of the cost), which brings them into the running for consideration given a certain importance being put on cost efficiency, and the desire for this system to be available to household users.

Plano-Convex Lens

Like bi-convex lenses, plano-convex lenses are also cost efficient, easy to source, and are able to converge light along an optical axis. Plano-convex lenses, however, come with the added benefit of decreased spherical aberration as imminent light can be directed to be incident on a flat surface. We originally planned to utilize the Thorlabs LA1540-A lens in our design since it had parameters that met required specifications needed to collimate our input broadband light source and it is suited for a compact design. But we decided to utilize the Thorlabs LA1951 though since it met required specifications to collimate our three select LEDs and produce a beam radius that fell within the volumetric constraints of our water sample. This specific lens also has an anti-reflective coating in the 350-700nm range which will help maximize our optical transmission.

Table 6.12: Plano-Convex Lens Specifications

Item #a	Diameter (mm)	Focal Length (mm)	Diopter	Radius of Curvature (mm)	Center Thickness (mm)	Edge Thickness (mm)	Back Focal Length (mm)	Cost
LA1540-A	1/2"	14.9	+66.7	7.7	5.1	1.8	11.6	$33.83
LA1951	1”	25.3	+39.4	13.1	11.7	1.8	17.6	$25.77

Lens Conclusion

The objective is to achieve a proper spectral resolution at a low cost. The difference between an achromatic lens and a biconvex lens, economically, is not very drastic, and could offer a large change in potential aberrations and safety in the functionality of the spectral design. These lenses can be outfitted with or without anti-reflection coating, to increase optical efficiency in our system. Optical efficiency is not too large of an issue in the collimating of the light source, assuming that our light source is effectively dispersed into the desired wavelength for our output. Therefore, we can forgo anti-reflection coating for the input light into the sample.

For the output, optical efficiency may be an issue. There will need to be a comparison and balance of cost of anti-reflection coating to the benefit of more optical efficiency coming from fluorescence. As specific parts are compared, it is assumed that a simple biconvex lens will be ideal for the project due to its versatility and simplicity in use, as well as its proliferation and therefore slightly cheaper cost.

We ended up utilizing two LA1951 plano-convex lenses in our final product design. They were utilized in a plano-convex lens pair optical system to collimate and refocus the LED light. More details on the exact optical design are provided in section 7.

6.12 - Mirror Consideration

For the original spectrometer design, in order to increase the diffraction experienced by the white light exiting a diffraction element and then becoming incident to a plane, it was assumed that one should increase optical path distance. Note that mirrors were not utilized in our final product and that this section serves only to showcase the consideration that was given during our early planning stages for incorporating one in our final design.

Increasing optical path distance didn't significantly reduce intensity of the diffracted light, which was necessary for our sample to receive in order to then produce proper measurements. Ultimately, we were interested in the plane of diffraction origin and the plane of the diffraction's projection. In order to increase the distance between these two planes, we assumed that we could use mirrors. This would, at the cost of increasing a price tag, make the device more portable.

We were, of course, interested in plane mirrors which reflect visible light. This was so that we can comfortably predict what wavelength will be located where on the plane of projection, and that the angle of incidence on that plane of projection will be consistent. This is, as opposed to a curved mirror, with possible rotation with reference to the incident diffracted light, might nonlinearly reflect and become incident on the plane of projection.

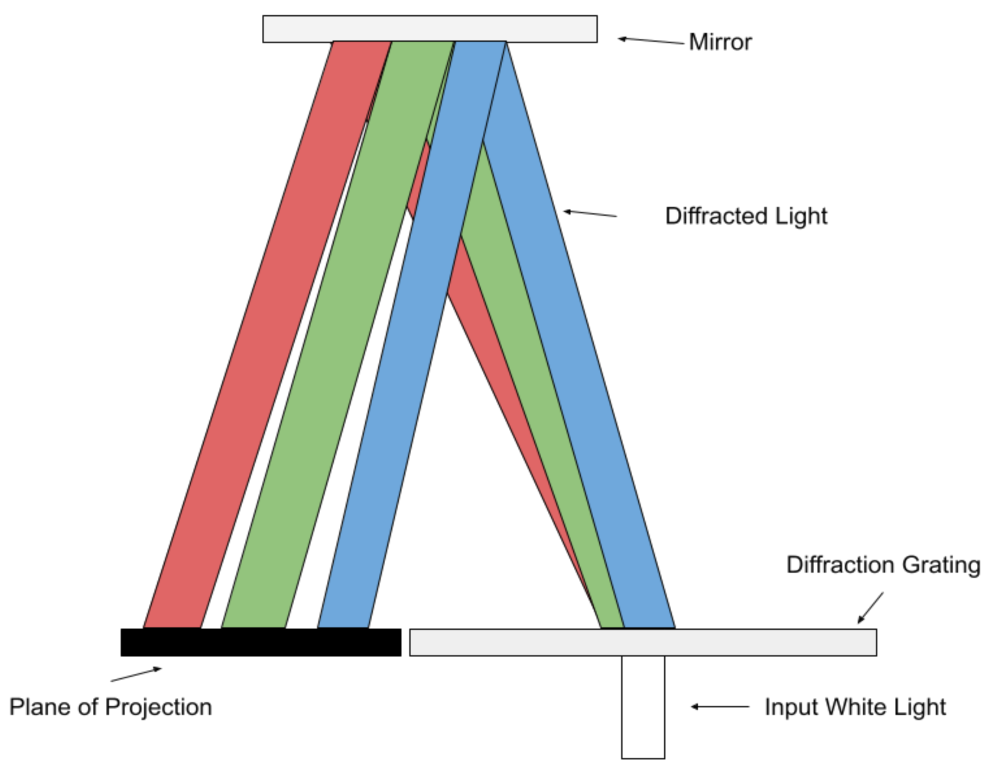
In order to utilize the incident light for the sample and those calculations, it would have been ideal to have a linear (and ideally constant) relationship between the portion of the diffracted light and the angle of incidence. Based on the initial boradband light source, who's emitting range is between 430 nm - 660 nm, we would have liked a mirror that has a reflection coefficient of at least 80% along that range.

We also took a look at the wavelength specific reflection coefficients. Mirrors have set ranges of wavelengths that they are optimized to reflect light in. Our initially selected mirror had a minimum 80% reflectance in the visible spectrum (450-2μm) to help minimize intensity lost through the varying optical components applied in the intiial design. Although, the mirror selected cuts a bit further into the visible spectrum, this should not have any notable negative impact on the device functionality as long as the reflectance for the UV-VIS boundary is relatively high.

We did find two mirrors which fit this description, and both were relatively cheap. Being found in Edmund Optics, they were both in an economy section of optical products, though they still boasted impressive accuracy in their construction. They are essentially the same product, but two different sizes. This difference between the two was expected to be resolved after calculation of the initial optical design, however it would have been ideal to have as large of a mirror as possible, due to the diffraction of the intended diffraction grating. The mirrors were also intended to be utilized earlier along the optical path length so that the same effect can be applied with a mirror of smaller dimensions. I.e. Most of the wavelength spacing were intended to occur after the mirror reflection.

These mirrors, which were coated with Enhanced Aluminum (intended for 450 nm to 650 nm wavelengths) are effective reflecting elements which could have added much more effect to our diffraction element while keeping the distance required along one spatial dimension limited if the diffraction element was still included in our optical designs for the end product. The principle of this addition is shown visually below in Figure 6.12:

Figure 6.12: Mirror Reflection of Diffracted Light



As seen above, the mirror greatly adds to the diffraction of the initial diffraction grating element, which, when considered as a whole with the mirror, would have provided effective diffraction for our purposes. The specific mirror that is being showcased iis the 30 x 30 x 5 mm λ/4 First Surface Mirror from Edmund Optics, and this would have been sufficient in area to properly reflect the diffracted light from the grating at the first mode. The specifications of this mirror were provided earlier in this document: in Table 6.43. The first mode would realistically not have extended too largely along the range of 5 mm, and could have been changed given a change in distance between the mirror and diffraction grating to both fit the mirror and provide an increase in the width of the first mode of diffraction's projection.

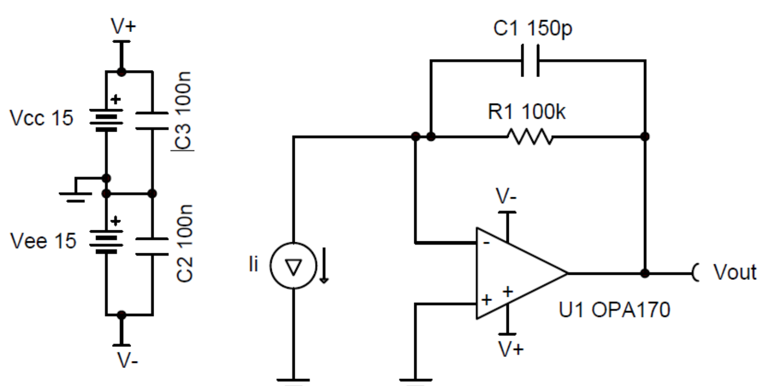
Given a value of merit of size or compactness on this optical-axis frame of reference, there will be a necessary impetus to use a mirror to increase the size of a mode of diffraction relative to the utilized length of the optical axis. This could be due to a necessary change in where hardware would need to be placed, whether it be on the far or near side of the optical axis, depending on dimensional necessity. Again, as mentioned in the introduction to this section, although mirrors were heavily considered in our original design plans, they were not at all included in our final product.

Phototransistor & Amplifier Design

The phototransistor we are using is Vishay Semiconductors' Silicon NPN Phototransistor, BPW77NA. This phototransistor has a good resilience to maximum voltages and currents, which made it easier to work with while designing our device, meaning we would be less likely to break it. Additionally, it works well in the visible spectrum wavelength, which is essential for our spectrometer. The stats to this phototransistor is found in the part research section.

The output from the phototransistor is an essential step in accomplishing our measurements. The phototransistor in question, which is how we transform optical power transmitting through our substance into electrical current to be able to be read in our circuit, only outputs a small amount of current. In order to overcome the limiting factor of the photodetector current, which would only output voltage on a scale of millivolts to be read by a voltmeter, we construct a transimpedance amplifier circuit, which can be seen below. This circuit can amplify this voltage to up to 10 volts.

Figure 6.12: Optical Amplifier Circuit



7 - Part Integration

In this section of our report, we consolidate the individual components outlined in Section 6 part investigation into our final optical and electrical designs. The technical purview surrounding the individual parameters of each component will be related to each other in this section to provide a better understanding of the final concept design and its working sections. Individually selected parts will be outlined in two separate sections: the optical and electrical design.

7.1 - Electrical Design

The device's electrical design is more about meeting standards rather than pushing limits; this is because the device's needs are much simpler on the electrical side than the optical side. For this device the electrical design needs to be simple, efficient and practical. This is because of the constraints of the design and the need to limit the workload on the small group. The device does not need extremely complex wiring and bells and whistles such as compatibility with smartphones or touch screens; it needs to analyze, compute and display data which are much simpler than the previous things that were mentioned to implement.

Power Supply Design

The power supply is one of the most important aspects of the design especially from the electrical side of the spectrum as the device needs to be powered at a specific stable current and voltage so that all components of the device work. With many different components in the device potential issues can arise from designing the power supply with different components requiring different levels of current and voltage.

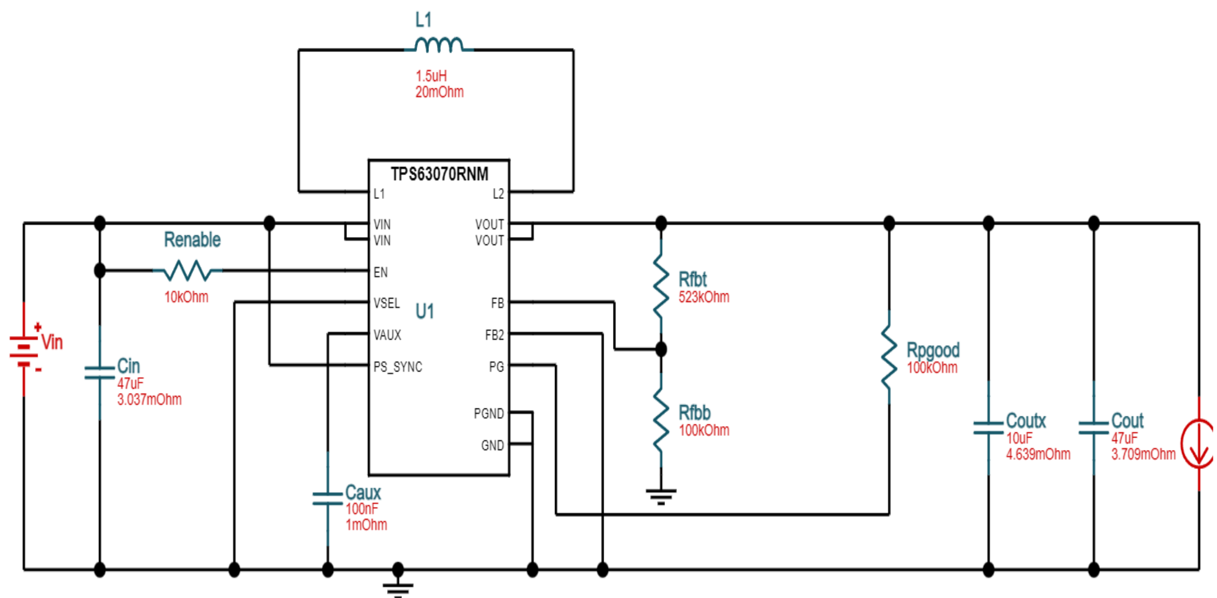
If components require different levels of voltage and current the design must account for that will converters and this can cause the device to become extremely complex in that case as the multiple components having different power rails. However for most components the voltage accepted is around 3.3V or 5V for this level of device so two different rails is better than 5 to account for. Another important aspect is the charging of the rechargeable battery and how the device will deal with battery supply power and how long it will last.

For our design several different components need power, these being the Microcontroller at 5V , the USB LED diode at 5V, the rechargeable battery that can be charged at 5V, the display device at 5V and as well as the photodiode at 5V. The majority of devices running at 5V simplifies the device a bit as it means that device can run from one 5V rail so we can just connect the specific components to the device and then the majority of the device will be powered. Connecting the input USB to the other components may be a problem as the USB power will most likely have to go through some form.

For the power supply design we used both Texas Instruments WEBENCH software and EasyADA the reasons for this are both simplicity and known by the members who are designing the power supply. WEBENCH would typically be sufficient for creating a simple power supply circuit however since we are creating a power supply with the ability to be recharged we need to use other software to create the charging circuit in Eagle with the Printed Circuit Board.

One main unexpected problem arose with the use of Eagle for PCB and Power supply design in that Eagle no longer exists as a sole application and has been included in a much larger and more robust Fusion 360 application made by the same company as Eagle. This causes some issues as in a short span of two years the user interface changed dramatically from default Eagle that was taught and used by the students before making a refamarility a necessary step in the process. As well as Fusion 360 seeming to be more unstable with multiple crashes when designing and importaning PCB files causing lost time and frustration to the team members that had to work with it to build the device.

Figure 7.11 - Power Supply for Peripheral Devices



The above design is a work in progress as the charging circuit needs to be created but the above power supply uses a 4.2-5.2V input to output 5V at 0.5A this is for all the components. The above design will be connected to the overall PCB to power the device. The rechargeable battery will be connected before the output of the current so that the power supply can charge the Lithium Ion battery at 4.2V. The voltage input and output were determined by the various components that the device will be using but the main component that was used to determine was the USB connector that will be used to connect the power.

After online research it was shown that a USB connector can supply a range of 4.2-5.2V so that determined the input of the device. All the components showed a particular need for 5V and since that is the range of the input we are in the clear. Another great part of our components is that they all need 5Vs so that they can be run off a single rail and there does not need a converter for any of the components to be powered sufficiently.

The power supply by using a 4.2-5.2V voltage input that will be supplied by the USB input that will be soldered onto the main PCB board. The will go to a boost converter in the middle that uses Buck topology to convert the input into a usable voltage and current for the components of the device. The converter makes sures that the components get a constant current and voltage so that they can run correctly and safely for each component.

With the use of the tool WEBench we can quickly create and design our power supply by putting in various things that we need from our Power Supply such as the needed voltage and current draw that is required to run the device. Texas Instrument, the creators of WEBench, then use their built-in library of power supplies to create a usable and efficient power supply that works for the criteria the user uses. This makes the creation of a working and usable power supply as most of the work needed is now based on the research phase of development rather than the implementation phase.

PCB Design

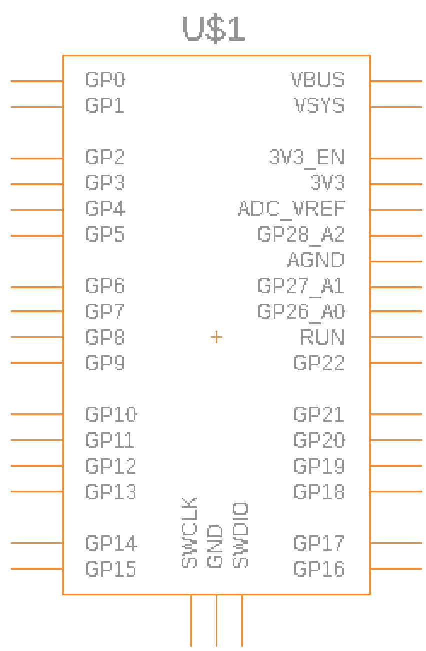
The Printed Circuit Board is the central hub for the device which will connect all of our relevant components to each other and be a large footprint for the interior of the device. The PCB is one of the most important if not the most important part of the device especially for the electrical side of the project. The PCB needs to be able to connect all relevant components, power various components with help from the power supply design, and be compact enough to fit inside the chassis of the device so that it can be secured.

The PCB design for the project is heavily simplified as for this project its main purpose is to supply support to the optical side of the design. The support nature of this PCB lets it be much more toned down with features and bells and whistles. This lets the PCB just do the bare selection of tasks that are needed for project success.

The main aspect of this first initial PCB design is to get all the relevant footprints on the board of the various components. Many components have unique footprints which require the members to obtain from their respective companies that create them. An example would be the MCU as the MCU is extremely important; it's equally important to get an accurate footprint for the device.

Overall the PCB is gonna be the hub for all of our components so that they can be in one convenient place and be powered. An important aspect in the design that is outside of normal electronic design is size of the components. To make the device portable and match the design size contrants an important balance must be maintained. Making the PCB too small and the components will not be able to fit with the necessary wires to make them work but make the PCB too big and it cannot fit in the device make it worthless and a bonus of making it more expensive to produce as well. An advantage to the PCB design that we are expecting to go with is simplicity in that it does not have as many parts to work around so the size of the PCB design will not be as much of an issue.

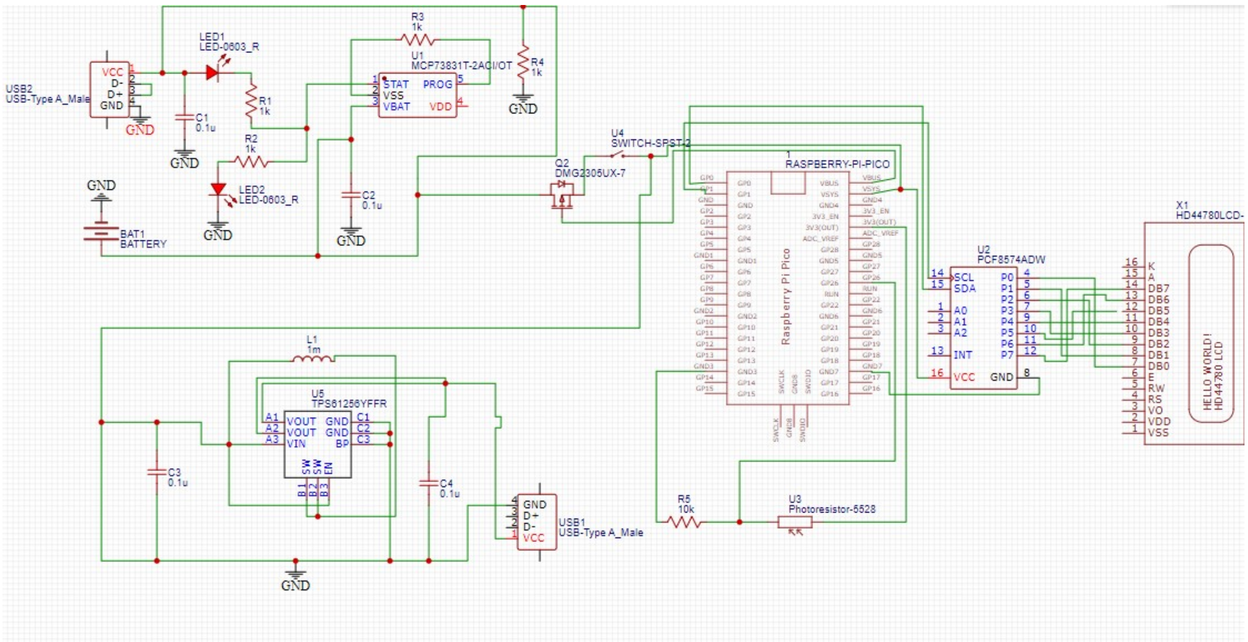
Figure 7.22: Raspberry Pi Pico Example Schematic



The following PCB design is a early prototype of the potential final design because it have to go through various redesigns and edits throughout Senior Design 1 and Senior Design 2 to make sure that the PCB meets final selection and will work as intended and not with potentially harming either the project, the consumers or the members of the project that are working on it.

Another reason is that some parts have different files and formats for PCB software. A notable example is that the Raspberry Pi Pico doesn't have official Eagle files for its PCB software, this is because its a Linux based system instead of being Windows based like Eagle is, which requires extensive research and development to make sure we are getting the correct files with an accurate footprint that could be used by our PCB manufacturing company when it comes time to print the boards.

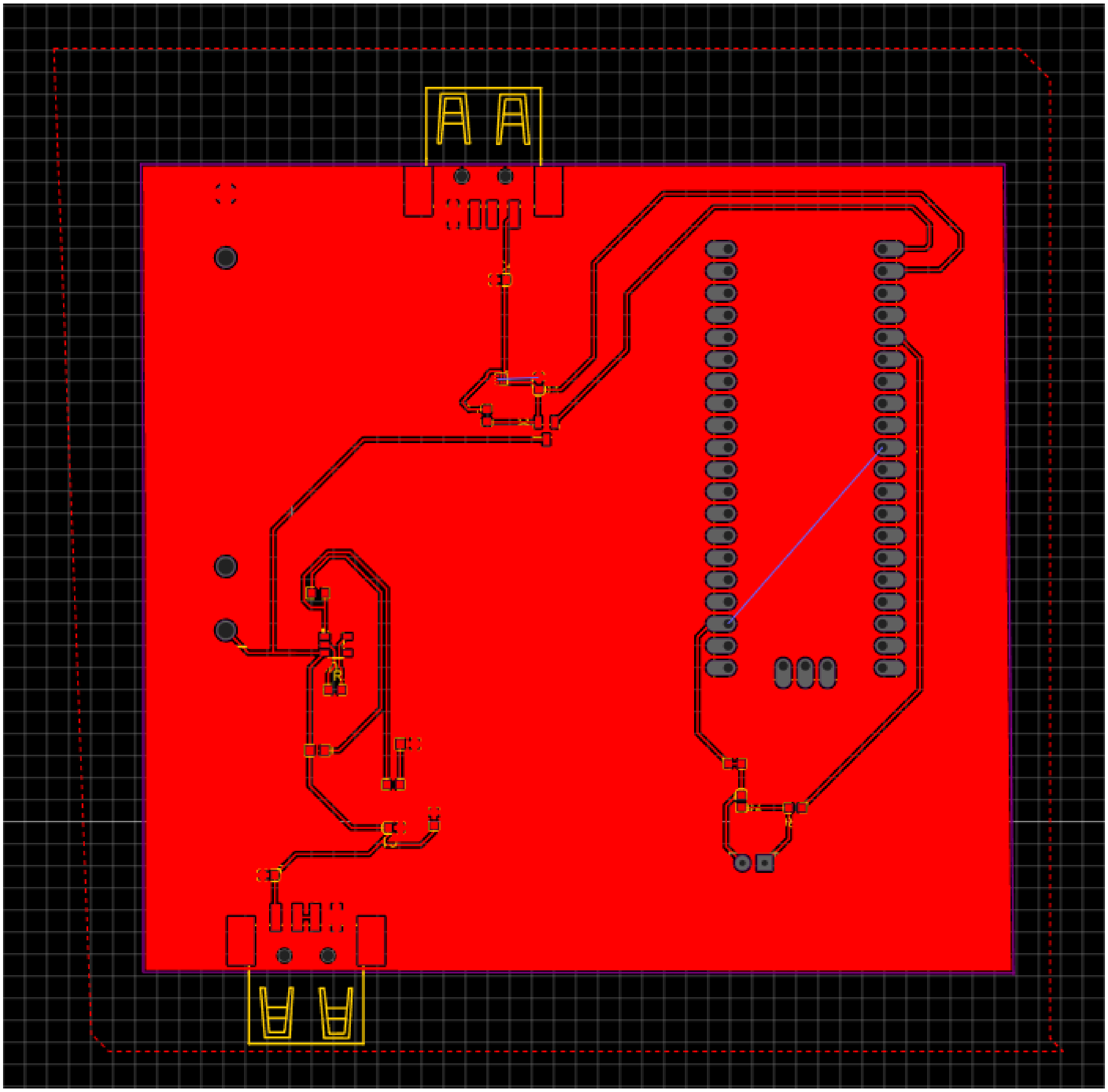
Figure 7.23 PCB Schematic:



The PCB shows the main components that are a part of the device in EasyADA. The bulk of the device will be the power supply as this is how the device will function as is. The next largest section is the connectors to and from the MCU. This is because the main various components need to either send or receive info from the MCU and this is important to make sure there is applicable room to achieve this feature. The display here is represented as a standard LCD display in EasyADA connected through SPI into the Raspberry Pi Pico. The connectors that are needed can vary from display to display especially when we get into higher end devices, however for our device the HD44780 IIC I2C1602 LCD Display was used which uses SPI interface.. The two USB type A connectors are necessary for both powering the device and connecting the LED light that was determined to be used at 5V.

When creating a PCB there are two main parts of the process: the schematic creation and the board creation. The schematic, seen above, is shown as a more conventional circuit diagram with long lines and circuit components in the background. The main use of the schematic is to show theoretical locations of devices and how they connect. The designers use it to show how the components connect and how they connect however there is no need to take into consideration how the device will fit in an enclosed space as wires are allowed to go over each other and cross whenever they are needed to. It also allows for the program that is being used to create them typically time to troubleshoot the device making sure wires and connections make sense and work as intended by either the creators or the manufacturers.

Figure 7.24 PCB Board



The second part of the PCB creation process and the more difficult and important is the board creation. The board file is typically seen as a red shape with green components on it with vibrant red lines denoting wires. An example can be seen above based on what the power supply for the device will look like by itself as a board. The board process is more important as this is where active constraints affect the project and theoretical values must become reality as this is the file that will be sent to the PCB manufacturers to actually print. This means that for the designers of the PCB must make sure that everything is correct and working on the software as by the time the pint is ordered, made and finally devlieverd weeks could have passed and if the process at the end does not work it means a large amount of valuable time loss. For this project the main issue that may arise from working on the PCB Board itself is the use of accurate footnotes and size comparisons. To make sure the PCB fits within the designed chassis that the group is developing, the file must be created accurately and told to the PCB manufacturer. These are problems that real engineers must deal with in modern work environments so this will be helpful knowledge to know and understand for future work commitments.

PCB Fabrication

When designing a PCB an important aspect of the design process is twofold: first what are you going to use to create and second, who or what company will you let create the PCB in house. A PCB is a type of electrical component that would be extremely difficult and time consuming to create yourself because most companies and engineers use outside resources to print their boards. This allows the PCB to be created by professional engineers and machines that will make sure the PCB will arrive exactly how the customers want it to. For the software side there are many types that can be used, two common ones being Eagle and Altium. For the sake of this project Eagle will be used as it is more familiar to designers and more than enough for a project such as this and allows it to be with print shops around the country.

In fabricating and manufacturing a PCB the way it is done through file sharing. In each PCB software the ability to download and save the files is relatively simple, however both the schematic and PCB files must be shared to the PCB manufacturing company in order to make sure they give an accurate and correct PCB board. The files most companies ask for are the Gerber files which are simple enough to get from your PCB software such as Eagle. Once most PCB manufacturers will then ask for specific information about the orders that may not be clear such as color of the solder mask and silkscreen, size of the board, and how many will be needed. Once this information is collected and sent and paid the manufacturer will begin on creating your board and once they are complete with your order send it to you in a timely fashion.

Since the design team live in Central Florida it is important to select a Electronic manufacturer that is local to the area so that shipping is reasonable for the team as it is more than likely that there will have to be multiple boards bought and used for testing as the inexperienced of the team may result in boards being damaged or even broken beyond normal repair.

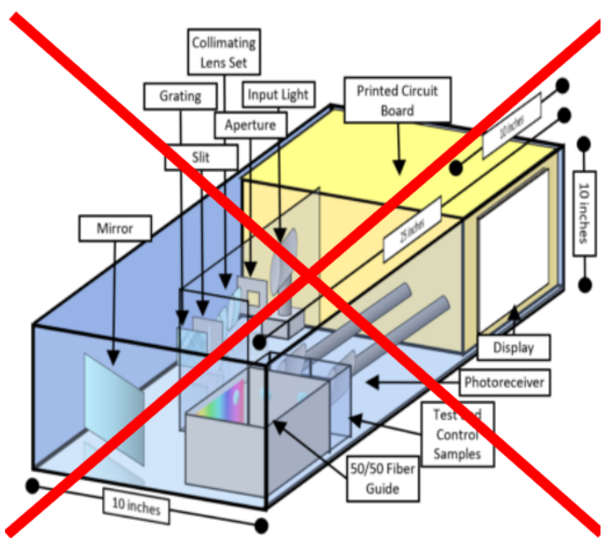
Central Florida being a tech savvy place means that there are several electronic manufacturers near that can be used. With a compulsory google search we find that there are three that have positive google reviews that we can use for our project; these are Jaycon Systems, Saturn PCB design, and Quality Manufacturing Services. These three all fit the criteria needed to fabricate our PCB. Choosing between is more difficult as the main issue would be price, however price is dependent on the PCB and since that has not been finalized it's hard to get an accurate read on which is best for this project specifically.

The choice of who to have the board printed by was JLPCB. The main reason they were chosen is reputation, price and accessibility. JLPCB is a Hong Kong based PCB manufacturer that has been used by many senior design teams for some years now. The main reason being is the integration into their Schematic software on their website EasyADA. This integration lets users go straight from the schematic phase to ordering the PCB within minutes. This makes the steps of making a PCB much easier. This along with recommendation from other senior design groups made JLPCB an easy choice. However there is one glaring issue with using JLPCB that is delivery time. Since they are located in Hong Kong it takes potentially several weeks to get your PCB back to you. With good planning this can be mediated however if at last minute your PCB breaks using JLPCB would be impossible so it requires a good amount of forethought.

7.2 - Initial Electro-Optical Design

Included in this section is the initial electro-optical design we considered for our device. This is the design that was intended to incorporate spectroscopy concepts that we later discontinued during later revisions of our product objectives and goals. We will be explaining how we intended to integrate both the optical and electrical designs into one consolidated unit for the initial design. We will also be providing schematics of our intended end product that are based off of our original design specifications provided earlier in this document. Note that the details in this section were entirely scrapped and is only being included for transparency purposes in our designing endeavor.

Figure 7.21: Initial Electro-Optical Design Schematic



The entire design was meant to have dimensions no larger than 30 x 15 x 16 inches. Using optical techniques to shrink the optical design however, like the use of mirrors to decrease the longitudinal optical length, we were able to compact the optical design to take up less space. We were expecting our initial design to encompass a range of 25 x 10 x 10 inches along its spatial dimensions.

The printed circuit board block encompasses all electrical components outlined in this design document. The optical to electronic interface will consist of USB input devices from the input light source and photoreceiver components respectively. The photodiode and transistor optical components will be connected via a USB-mount device that allowed us to attach it to the PCB.

The use of a mirror and a fiber-optic guide cable was considered to allow us the flexibility to direct the light in a spatially efficient manner. The selected lens pair was considered to allow us to collimate our input light source within the shortest focal length pair available to us. This further helped us to achieve a plan for a more compact design. These aspects were specifically taken into account in the planning phase. The device is meant to be compact for retail use. With the initial expected design specifications, we were not expecting to meet our initial design goals which led to our later revisions.

By designating a single portion of our device as the PCB we realised the following benefits were possible:

- All of the optical components are centralized to a specific part of our design, allowing quick access to them for any troubleshooting needs.
- The photodiode, phototransistor, display, power-source, and user-input periphery components can all be directed towards a single direction for their connection ports.
- All electrical components are centralized to a specific area of the device, allowing for easy and quick access for electrical troubleshooting.

The PCB was intended to be designed with the limited space in mind. The PCB was intended to make sure the USB connectors that are needed for both the power supply and the light course are on the correct side. In respect to the display being the front of the device, the USB that is for the power supply will be on the back and the USB for the light course faces the left to make sure it is connected with the light source it's powering. The PCB design was then to have the power supply and MCU interconnected.

Overall the PCB was expected to encompass the power supply, the MCU, and the battery, however that is the bare minimum of space that the MCU will need to function. An important aspect is to make sure that the wires that are gonna be necessary for the components to function. The MCU for this device will not be embedded so it will have wires connected instead of having it in the PCB itself. The most important aspect to both make sure the device works preferably and that it is safe to operate. To accomplish this the device was expected make sure the battery and the MCU are a safe distance away from each other.

None of the details included in this section that included references to spectroscopy, gratings, or mirrors were utilized in our final design. An outline of our final electro-optical design has been provided below which contrasts in several ways to the initial plans curated throughout Senior Design 1.

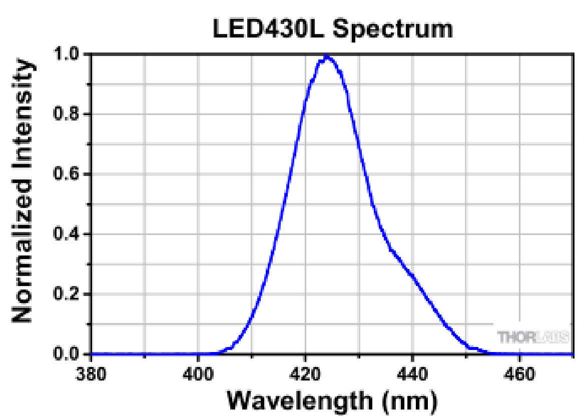
7.3 - Final Holistic Electro-Optical Design

This section outlines the electro-optical design utilized in our final end-product at the end of Senior Design 2. Included in this section is also our revised optical design that was also revised.

The diodes selected emit light at wavelengths that maximize the absorption effects of both Chlorophyll A and B but also provide enough bandwidth to allow the device to differentiate between the two if both substances are present in a single sample. For example, the red LED at 660 nm was selected due to the high absorption of Chlorophyll A in contrast to Chlorophyll B which has practically zero absorbance at that wavelength. Due to the broadband nature of our LED, however, which emits light in a range of approximately 30-40 nm, we can still detect absorption effects of Chlorophyll B using the 660nm red LED. The varying wavelength output intensities of each selected LED, were taken into account, which were provided in the device data sheets.

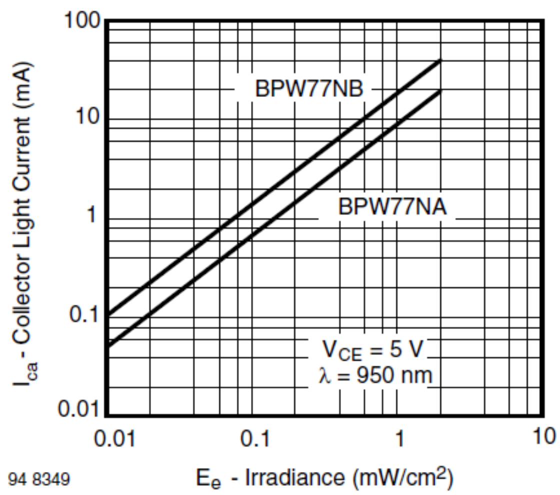
The light intensities read by the photodiode for the control and test samples were accounted for in the wavelength specific variations of the input light source as well as the responsivity of the selected photodiode. The figures below showcase the output spectrum of the blue 430 nm LED and the wavelength responsivity of the selected photodiode. Already, we see variations in chlorophyll absorption, LED emittance, and photodiode receptance spectras: all of which were normalized to produce consistent measurements utilizing three distinct wavelength groups at 660 nm, 505 nm, and 430 nm.

Figure 7.31: Light Output Spectrum (430 nm)



This figure showcases the LED430L normalized output intensity. This spectral profile varies from LED to LED and will be accounted for when calculations are performed by the microcontroller unit to calculate impurity concentrations.

Figure 7.32: Phototransistor Response (BPW77NA)



This figure shows the response of the collector current to irradiance incident on the phototransistor we are using, BPW77NA.

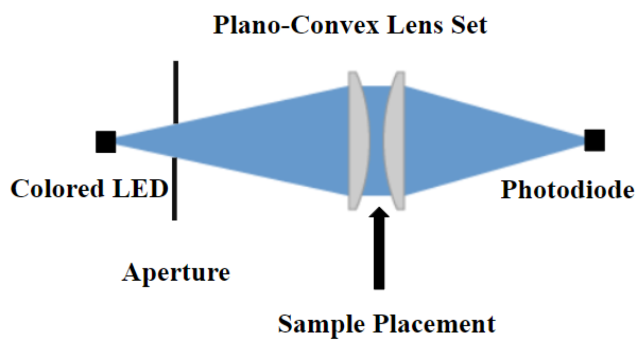
A control sample is utilized in our design. This control sample accounts for any transmission influences due in part to the water or glass container that each sample will incorporate. This allowed us to place additional emphasis on the independent variable, the chlorophyll in each test sample, as the only variable being changed in each test by our device.

Care was given to interpreting the results from the control sample to understand concentrations to other samples, however. In the figure above, one should note the logarithmic relationship between incident light and the current output, which could be tricky to anyone wanting to accurately interpret measurements on the output. With the logarithmic scale in mind, we were able to more intelligently set control concentrations, where we can provide a guide to users based on informative tests that we carry out. This ensured proper and accurate use of the wavelength absorption dependence detection of chlorophyll.

Since our wavelength specific LEDs have a viewing half-angle of approximately 20 degrees, which is the point where the intensity of the light is exactly one-half what it would be at 0 degrees, we utilized a set of plano-convex lenses as part of our optical design. Using 25.4 mm (1 inch) diameter lenses with a focal length of 25.4mm allow us to produce a collimated beam of light at each 430, 505, and 660nm within the diameter constraints of the collector lens when the lens is placed a focal length’s distance away from each LED.

The use of plano convex lenses, allowed us to collimate our LED light, pass it through a predetermined volume of a water sample (approximately 38cm^3) hosting a concentration of chlorophyll, and collect the transmitted light to direct towards the photodiode receiver circuit. According to our calculations, if we treat the LED as a point source, and filter out excess light traveling outside the viewing half-angle of the LED by way of an optical aperture, by placing a 25mm focal length plano convex lens one focal length away from the LED, we can create a collimated light source with a beam diameter of approximately 20mm. Our lenses were selected to have diameters of 25.4mm, so all of the emitted light can be collected by the secondary plano-convex lens. The focal lengths of each lens were hand selected so that the size constraints of our design objectives could be met.

Figure 7.33: Final Optical Lens Design Schematic



This figure showcases the optical design utilized in the device. A plano convex lens set is applied to collimate the LED light within the constraints of a 25.4 mm beam diameter. Note: this figure is not to scale. Also note: the optical design is applied in a top-down vertical fashion in the construction of the end product.

Give an expected collimated beam diameter of 20 mm throughout the area of the sample placement. We calculated the expected volume of light that passes through the water sample given a sample length of 30 mm. The volume where absorption takes place is approximately 20cm^3. This value is utilized within the device's microcontroller unit in coordination with the Lambert-Beer Law so that theoretical predictions of chlorophyll concentrations can be determined by the device.

In the device, the optical components are positioned vertically. The LED illuminates the sample from the top. Each lens is held in place by the chassis against gravity so that the angular, lateral, and longitudinal placement will be secured. The sample is able to be adjusted, removed, and replaced without interfering with any of the peripheral optical components. By doing this, we ensured that the optical design remains on-axis and that no additional variations between the tests are added with each sample test. This allowed us to perform one 'control' test with a distilled water source, whose measurements and data will be stored within the microcontroller unit, to reference against any following sample tests.

The optical design is fully encased in a 3D printed chassis. The chassis will be completely oblique, to block any excess ambient light from interfering with the device photodiode measurements.

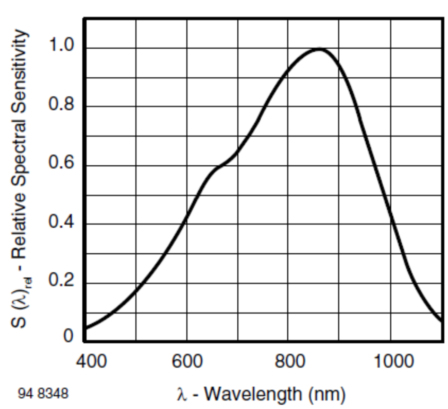
Previously, we discussed the intelligent use of the light moving through the system. Now, we will discuss the way that light will be utilized in producing a measured output. This is done by the utilization of the subject of photosensing. Some technologies in this field use different strategies than others.

Photoresistors are an example of this technology, and they involve using a material with valence electrons sensitive enough to incident light that they are ejected from their parent atom and join the conduction band. Light is therefore measured by the degree of conduction of electricity through this material. Photoresistors are not semiconductors, like the technology we used, and are also less light sensitive than we desired [3].

For this design, we decided to utilize the concept of photodiodes, specifically the technology of phototransistors. These are semiconductors that are sensitive to light. Photodiodes, being semiconductors, have PN junctions, which react to incident light by producing a photocurrent across the device, which provides current to the circuit, which can be measured.

Phototransistors are different from photodiodes in that they involve different constructions of their junctions. Photodiodes are usually either PN or PiN junction semiconductors, and they involve a smaller photocurrent generated from incident photons. A phototransistor, however, is a bipolar junction transistor that is of the form NPN most popularly [5]. An NPN phototransistor has an amplified photocurrent due to its construction. Because we are looking for the largest photocurrent to take in and measure, we chose the phototransistor.

Figure 7.34: Phototransistor BPW77NA



This is the relationship between incident-light wavelength and sensitivity of the phototransistor, relative to its sensitivity at a wavelength of 950 nm. The phototransistor we are using is Vishay Semiconductors' Silicon NPN Phototransistor, BPW77NA. This phototransistor has a good resilience to maximum voltages and currents, which made it easier to work with while designing our device, meaning we would be less likely to break

it. Additionally, it works well in the visible spectrum wavelength, which is essential for our spectrometer
.
Above is a graph from the specifications sheet for the phototransistor we are using. It shows an effective spectral sensitivity across our desired wavelengths, with a conversion factor to ensure these wavelengths are measured with consistency according to their effect on the phototransistor.

The nature of phototransistors is that very little current is created from the photosensitive area. The active area is small, and the semiconductor can often have a very small acceptance angle for light, which further decreases the efficiency of photocurrent creation. This is why an amplifier circuit is necessary to resolve measurements from the light resulting from the absorption process in the water/chlorophyll.

This circuit involves the creation of a photocurrent in the phototransistor, which moves through the circuit to then be amplified across a resistor to be measured as a voltage. This voltage is taken from the amplifier circuit to be measured later. The circuit in question is more electrically defined in section III, “Electrical Design.”

Effectively, what is output is on the scale of millivolts if it were to be read across a resistor on our voltmeter. With an amplifier, we aimed to get the voltage to a scale of 3.3 volts, which is a specification of our design that is due to the functionality of the Raspberry Pi Pico. The amplifier is actually capable of converting the small and difficult-to-read current from the phototransistor to up to 10 volts when read across the output. This would be too much, so we decrease the voltage supply across the operational amplifier to achieve our intended voltage scale.

8 - Administrative Content

With design, one of the most important aspects that is not strictly designed based on the aspects of administration.The following paragraphs will host information regarding the administrative nature of the design process will be outlined here for the reader’s significant awareness. Details surrounding group management, communication methods, and team dynamics will be provided.

8.1 - Communication

In any group project, communication is a key aspect to success. Members of the group need to be in regular contact with each other so that group time goals are both met and set in a timely and orderly fashion. Various forms of communication were used in the group these being SMS messaging, Groupme, and Google Docs. The group members are also all a part of an extracurricular organization that they were able to meet fairly often in person to talk about the project.

SMS messaging

SMS messaging was probably the most used and most common way group members contacted each other throughout the project. Group members have had each other's phone numbers for years through various means of prior plans and obligations. SMS was mainly for when a response was needed as soon as possible or when other forms of communication were being unresponsive.

The main advantage was the responsives from the members in that the SMS sending an alert straight to one's phone meant that it was hard to miss. However the biggest disadvantage was that typically these were one on one conservation meaning that typically one group member may be let out of the loop and this could cause a problem with potential miscommunication down the road in the project. If everyone were not in the loop on any particular conversation, a subsystem that could relate to other parts of the project could be designed with poor input and output specifications, and could need to be completely redone, costing time and effort in order to make up for a miscommunication. In order to find a proper line of communication for the group to use for the project, we will need to look for a communication system that can involve the entire group at the same time.

GroupMe

GroupMe is a common group messaging app for the modern day allowing users to create groups for any rhyme or reason. The team created a group before the beginning of the semester to make planning and coordination easier in the upcoming project and paper. GroupMe messages arrive just as normal SMS or text messages for many users however they tend to not be seen either as urgent or through the use of settings as easy to notice. The nature of this messaging app is that so many groups in our community use it, so it is easy for a single group in this software to be drowned out by the communications of many other groups who may constantly communicate with each other.

Groupme was used throughout the semester however communication tended to become more verbal and in person as the semester went on. The greatest advantage of using GroupMe was that every person in the group could see what was being said, meaning that the group was all kept in the loop. Users can be called out individually to notify them with greater urgency about specific messages, and documents and links can be easily shared between users, making it a good platform to interconnect other aspects of the project, like items on Google Drive. However the greatest disadvantage is the ease of the messages being ignored and because of how Groupme works sometimes other groups in the same app can take priority which can bog down communication for some team members throughout the project. When using Groupme, our group was necessitated to consciously keep communication in mind, as we understood this weakness that Groupme has, and we could not let ourselves think that Groupme was going to bring important communications to the front of our notifications every time. It still worked as a perfectly free and interconnected platform for discussion, despite the shortcomings.

Google Docs

Google Docs is a collaborative writing software that is free to use that is very similar to Microsoft's Word software. Google Docs is the main way that the group members wrote a majority of the paper as it lets the users share and work on the paper simultaneously without having to actually be in the same vicinity. Communication was of course vital using this piece of software however communication was typical through the use of notes that the user left each other in the document.

Notes let group members express their opinions about various aspects of the project especially the paper and help explain things about the paper to some group members who are more lost than others. Using Google Docs notes was the most direct way to ask or edit a piece of the paper without just editing the words. This lets the group have a more collaborative way to write the paper and leave suggestions; this is the greatest advantage. The biggest disadvantage of the notes on Google Docs is that they stay on the paper even after downloading the paper making it harder to read unless you delete them all and sometimes it would be better that the professors do not read what we are putting in the notes as they could potentially be unprofessional.

Email

Our last form of communication was email. Email was largely employed when specific documents or references needed to be shared between team members. The powerpoint presentations required for the senior design lectures were also collaborated on and shared via email. Lastly, communications with our professors to schedule our periodic report reviews were all managed via email communications.

9 - Standards and Constraints

In order to successfully construct any technically complicated system in the modern world, one needs to pay attention to proliferated standards that allow for an interconnected technological framework, which allows for different technologies to be developed and cheaply produced. Time, money, environment, manufacturing, safety and health concerns need to be thoroughly considered prior to making a technology a reality to make sure it has a place in the market and its use in society.

9.1 - Economic and Time Constraints

An important aspect of project goals and expectations to set are constraints that are set by the environment of the project and the members. These constraints can range from : economic, time, environmental, societal, political, ethical, health and safety, manufacturability and sustainability contranit. The constraints and how they will affect the project will be discussed in the upcoming paragraphs in relation to the device and its creation.

Utilized Light Spectrum

In considering the function of the project, UV light was considered for use in spectrometry for water impurities. Many inorganic impurities had notable absorption or raman scattering signatures within UV light which would make it exceptionally useful to use. When going about trying to build a prototype, however, our group quickly noticed that these EM wave signatures were along the spectrum of far-UV, in terms of wavelength. The most commercially ideal form of UV is near-UV, which is nearly within the visible spectrum. Far-UV light sources would have cost about ten to twenty times the potential cost of using visible spectrum light sources for spectrometry of these impurities, even when including components to mount the visible light source (a white light LED) onto. Given this difference in cost, there was an impetus to transition to visible-light spectrometry to make something much more affordable for our intended use of the project: household use. If far-UV light was used, there would be no way to make this device even within the ballpark of common commercial affordability. Not even mentioned was the sort of detectors necessary for far-UV spectrometry. Visible-spectrum light would adhere to the constraint of affordability and economy.

Time constraints naturally play into this problem we have. Of course it would be easier to go with the more easily accessible research on far-UV spectroscopy of drinking water impurities, however it would be a breach of our economic constraint. Attempting to make use of visible light would play against a time-constraint of our group, where a system design and function must be developed within a certain time frame. With this in mind, the decision to use visible light was still achieved by our group, as there would be enough time to make some functionality for three colors of visible light, but there may not be enough cheap options in the far-UV utilization of spectrometry to fulfill the economic constraint.

Light Source

In terms of the light source, three colored LEDs were chosen for reasons described above. These LEDs will need to be powered with a DC power source. According to our experience working with such electronics, there could possibly be more complications and time-sinks to the project, like needing to learn more about these electronic systems or troubleshooting unknown issues that might arise. This could add complications to the surrounding system as well.

System Display

When it comes to the system display, much time is required on any individual's part to research and come up with a strategy for an ideal display for the system to be accessible to a consumer. Given our project's staffing, this time requirement may not be feasible, depending on the quality desired by the display. Because of this, the core components of the project have been prioritized, and the display aspects of the project had been put to a later priority to possibly be compromised upon due to the constraint of time for development. Economic considerations also tell of difficulties our group could have if we were to include a display screen that could be easily programmed, versus some other more analog readout strategy. This is why we eventually went with an LCD display which connected easily to an MCU.

Optical Design

The optical system requires little time or money, relatively. Optical design is more streamlined in our group's skillset, and the requirements for our design are very simple: most of the light emitted from the light source must be collimated within a known radius to be put through a sample. Given a statistic of an angle, under which most of the power emitted is, we can determine this through a simple ray-tracing diagram. This may be easier and more accurate with a software light Zemax, however said software is extremely expensive, so that is not ideal. Using ray-tracing strategies using excel is possible, however, or even using a ray tracing matrix, given the simple nature of our design intent. This is free and easy, so there is no reason not to employ these in our design strategy, and they were used in order to call for the qualifications of a collimated beam.

After having decided for the qualifications of the beam, there was a need to find the best-fit lens to use for the collimation. In the economic scheme, it was ideal to find a cheap lens that also had details about its manufacture, focal length, refractive index, and other such descriptions readily available for use in our equations. While there are lenses that are meant for education that could be a tenth of the cost of a standard uncoated lens from Thorlabs, the only details about their construction is a focal length. This could provide a poor quality product, as well as cause complications in the future, which would consume more time. We ended up going with Thorlabs lenses which were of good quality and economy.

Electrical Design

The electrical design of this device is very simple. This is because the needs of the device are not on the high end for an electrical design. The main aspect of the electrical design is that it is needed to run the optical design, run the Microcontroller Unit to compute and collect the information and to power and display that information on the display. Even with this very simplistic electrical design constraints are still felt on even this level as a large aspect of electrical design, especially in the power design of the device, is part selection. That will be explained more in the coming paragraphs in more detail.

The electrical design was heavily influenced by the economic and time constraints of the project. Even though average electrical components and the sub systems they help create are on the rather cheap end of the spectrum when selecting larger components, such as the Microcontroller Unit, the price range can become an issue. An issue also arises with buying back up or spare parts. Anything could happen from parts becoming fried as the group members mess with the PCB and soldering so it's a near necessity to get spare parts which adds to economic constraints that are going to be exerted onto the group members for the project.

For time constraints in the electrical design some initial thoughts happen because of part selection being a major aspect that needs to be done early in the process so that the electrical design can really begin. Without parts selected it is impossible and useless to start creating a power supply. This is because without the knowledge of what voltages and currents that the device’s components, any power supply would be useless as it would not be able to do its single purpose. This meant that almost all of the electrical design had to be done towards the tail end of the design process as it relied almost entirely on part selection of the optical design; this was a major constraint on the time of the design.

9.2 - Environmental, Social, and Political Constraints

A portable, cheap, and effective drinking water quality sensor would absolutely fit the social climate right now. Especially given the amount of skepticism over the water quality in certain areas, there is a place on the market for an answer to people’s potential concerns for their tap water. Potential contamination of water processing facilities is sometimes seen on the news, for example. There are few social constraints that could oppose a visible-light spectrometer. There are social concerns, especially in California, with electromagnetic radiation, like that which is associated with cell phones or wifi devices. The mere fact that spectrometry is happening in the visible spectrum means that people are more familiar with this kind of electromagnetic radiation, which means they feel more safe around it, given they understand it won’t penetrate through plastics or even their skin to cause potential concern for health issues.

As mentioned in the previous paragraph, there is little to be concerned about with social or political constraints with a visible-light spectrometer like our group is producing. In terms of political considerations, there are no ways to misuse our device in any significant way. The visible light LEDs are not harmful in the slightest.

There may be environmental constraints to be concerned about, but nothing that would prevent the project from making it into the market. The components themselves would include some, but not any significant, plastic construction, and the power consumed will be on the scale of miliwatts, which should not be worrisome for power consumption for the environment. In the final product, there should be a box or set of walls that surrounds the construction so that excess light is interfering with measurements. This box could be made out of a recyclable material to make sure it is dealt with properly, like a recyclable plastic or cardboard. The difficulty would be making sure this excess material is recycled, or it could add to waste given the devices were thrown away.

Ethical Constraints

In order to make this system ethically responsible, the device should accurately and faithfully perform the task it was designed for. If the ultimate goal is to mark unsafe concentrations of a water impurity, then that should be performed with the knowledge that the user may not understand anything about the process or what the results even truly means. There should be care put into the product's reporting to make sure nothing communicated is in any way untruthful. To fulfill the constraint that is being fully transparent to the user about the process being undertaken, care needs to be put into the reporting process.

The report to the user of the status of their water will be given in terms of a threshold content value, and whether or not this content value is being surpassed by the sample. In the wording of this report, we should be aware that the user may misinterpret the results to mean other impurities may also be being detected or accounted for which may not be, for example. In this case, care should be put in wording the instructions or the user display (whichever may be more effective) in order to address this uncertainty in a possible layman's mind. If this project were to be described as a way to address all drinking water quality issues, then there would be an ethical breach occuring. Even if this were implied by exaggerations in the advertisement, it could be harmful to individuals who put their faith and safety in the hands of the product, and so one must go out of their way to make sure the user understands only certain kinds of impurities will be tested.

In constructing the device, the team should not be using others' intellectual property to make the design process more easy or possible. Ethical considerations obviously apply to the individual the product is designed for, but considerations must also be given to other engineers or designers of similar technologies that could be adversely affected by the improper use of their ideas or work put into their designs. This could cause issues in many different ways, the primary way being that compensation is not being duly given to the owner of certain intellectual properties that might be used, and other ways including that the concepts that are effectively stolen could be used incorrectly, which would then introduce problems due to poor implementation.

Health and Safety Constraints

As mentioned in a previous section regarding societal constraints, there are not any health concerns regarding electromagnetic radiation in the visible spectrum. The nature of the light being emitted by the light source allows it to be fully blocked by a very conventional framework that will surround the project for the sake of the project's functionality, which can then work similarly to keep project function out of interfering with its immediate environment and therefore possibly users of the project. Care can be taken to make sure every electrical component associated with the project stay out of the user's reach, so that there are no dangers with the circuits and a shock.

A highly potential danger in the health and safety of the device construction is the use of soldering for PCB creation. Soldering is the use of very high temperatures to melt metal and solder onto board parts. This will have to be done in various parts in the project such as the USB connectors wires to connect the battery to the PCB and other various electrical components throughout the project that safety is paramount for both the group members and the potential users of the device.

To compensate with these health and safety constraints the group members with the most experience will be doing the soldering and will be the only ones that will be doing it instead of forcing the entire group to partake in the device and potentially hurt themselves. For the use of soldering iron, the only soldering irons that will be used are the ones in the Senior Design Laboratory or the TI Innovation Lab at UCF. This is because these are trusted devices that have been used many times before for many Senior Design projects. Also along with the financial reason to use the facilities that are provided for free by the university instead of having to buy our soldering iron and filament which can add to the cost of the project when it would not need to be when there is a cheaper option available.

Manufacturability and Sustainability Constraints

If this product were to be manufactured in large numbers, there could be difficulties streamlining the optical system. There would need to be care taken to make sure the optical system, who's function is more sensitive to spatial variations, is aligned and safe.

In order to make this product sustainable in its manufacture, recyclable materials could be used where possible. These materials can, as mentioned before, make up the framework on the outside of the product. They could also make up the material used for masks or apertures used within the product, and any movement the project requires could be developed with other such cheap and recyclable materials.

9.3 - Standards and Regulations

In modern device construction various national or international organizations have created standards that all applicable devices must meet to become certified by the organizations. Consumers and other businesses take these seals by the organizations very seriously, sometimes not even buying or selling the device without them. These standards are typically created for consumer safety or to meet sustainability objectives by the organization or host nation to make sure that even an uneducated user cannot hurt themselves and that the device will not hurt the environment during or after use by the consumer.

Power Supply Standards

The power supply can be one of the most potentially dangerous parts of an electronic device especially when not made properly and handled by people who do not know how to handle it safely. The standard for the power supply that the device will be referenced is the standard by the organization, CUI, which specializes in power supply parts and information for electrical engineers.

The standards are based on a circuit classification of the power supply. CUI classifies the necessary circuit in the table below:

Table 9.1: Power Supply Definitions

Circuit Type	**Definition**
Hazardous Voltage	Any voltage exceeding 42.2 Vac peak or 60 Vdc without a limited current circuit.
Extra-Low Voltage (ELV)	A voltage in a secondary circuit not exceeding 42.4 Vac peak or 60 Vdc, the circuit being separated from hazardous voltage by at least basic insulation.
Safety Extra-Low Voltage (SELV) Circuit	A secondary circuit that cannot reach a hazardous voltage between any two accessible parts or an accessible part and protective earth under normal operation or while experiencing a single fault. In the event of a single fault condition (insulation or component failure) the voltage in accessible parts of SELV circuits shall not exceed 42.4 Vac peak or 60 Vdc for longer than 200 ms. An absolute limit of 71 Vac peak or 120 Vdc must not be exceeded.
Limited Current Circuits	These circuits may be accessible even though voltages are in excess of SELV requirements. A limited current circuit is designed to ensure that under a fault condition, the current that can be drawn is not hazardous.
Limited Power Source (LPS)	These power sources are designed with prescribed output voltage, current, power and short circuit current limits. Specific methods can limit the capacity of the power source. The requirements for wiring and loads supplied by LPS power supplies are relaxed due to the reduced hazard of electric shock or fire caused by an LPS power supply. Power supplies offered as conforming to LPS must have either internal power limiting provisions or external devices limiting current delivered to the load.

The circuit type that our power supply would be under is the extra-low voltage. This is because we are well under the specified DC voltage of 60V for the circuit in the power supply. The device will at most have 5.2V through the system as determined with the power supply design. To make sure that safety is paramount insulation will be used around the battery and wires that are soldered onto the PCB.

Lithium-Ion Battery Standards

Lithium-Ion is a relatively safe chemical compound for most applications, this is why it is being used daily in many electronic devices, however when handled improperly it can cause fires and potentially explode. This is why many organizations have procedures and standards for Lithium-Ion and similarly rechargeable batteries. The standard for that is applicable is IEC 61960-3:2017. The International Electrotechnical Commission outlines proper procedures for both consumers and engineers when creating portable devices.

Our device will be under this standard as IEC 61960-3:2017 is as follows “Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for portable applications” as our device is portable with a secondary lithium battery. The standard is about procedure when securing the battery in the portable device and making sure the correct size is used to minimize the risk when using the battery.

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