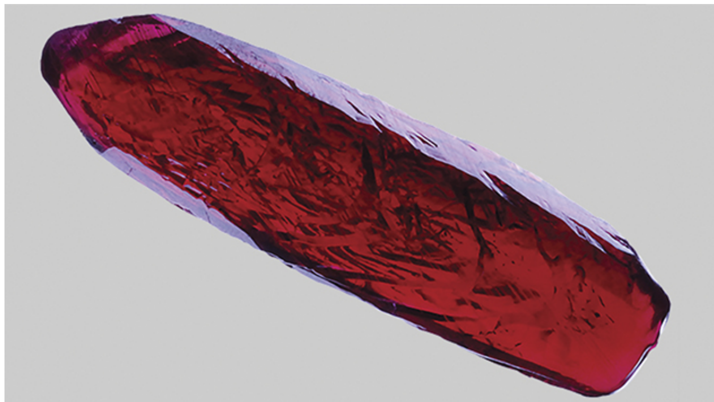
University of Central Florida
Senior Design I



Ruby Efficacious Imposter Detector (REID)

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Senior Design 1

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1 Executive Summary

As materials science continues to get both more advanced and accessible to the general public, gem fakes and shameful imitations are only becoming more prevalent and harder to distinguish. Many people take their expensive jewels to experts only for them to be imposters. Crystallography, the science of crystal structures and properties, is done primarily using optical instruments. However, rather than uploading images or spectra of the gems into a program and having more reliable conclusions, the most popular gemology methods are done purely by the expert's best judgment. A loupe is essentially a magnifying glass that looks for inclusions, but has no ability to record data. The dichroscope is very similar, however it separates out different polarized rays at different wavelengths. The difference between these wavelengths is up to the human eye alone. The dichroscope is often used in conjunction with a polarimeter, which determines crystalline structures of the ruby using two rotating polarizers. In addition, many novices simply shine a light at gems to see if they fluoresce. Our design seeks to focus on rubies and to make a multi-faceted testing system.

REID aims to remove the objectiveness of gem characterization through a proof-of-concept technological approach. It will combine the most popular forms of ruby identification tests, fluorescence and dichroism, and unify them into one system that will test specifically rubies and be able to tell whether its real (whether that be synthetic or natural) or fake (made of garnet, dyed quartz, etc.). This document has been written to delineate the process of creating this system. Other relevant existing designs will be described and compared to REID's approach. Once this has been discussed, then the relevant technologies that are or could be involved in REID's design will be explored in excruciating detail. Post research, the parts will be chosen based on the relevant knowledge we have at our disposal. Design constraints as well as the standards of this project will be outlined towards the end, which will include the optical, electrical, hardware, and software components. All copyright permissions and sources will be listed at the very end after the final conclusions of this project.

2 Project Description

2.1 Project Background and Goals

There are many methods for crystallography in the world today. Due to advancements in optical technology as well as knowledge of materials, there are many experienced crystallographers who can spot a fake with a simple UV light and a loupe. However, as fake and synthetic gems are becoming more prevalent and harder to distinguish, it is imperative that distinction methods become more precise and reliable. To amend these concerns, we propose a multipurpose system that will combine these sporadic methods into a unified system that will remove any personal bias or human error on the inspectors' part. We will design a proof-of-concept system that will have the goal of distinguishing real rubies, synthetic or natural, from fake (imitation) ones. The fluorescence spectra of the ruby will be captured via a spectrometer housed within an enclosed system, as well as verifying true trigonal crystal structures with the use of a dichroscope that will be implemented into the spectrometer. The live results of these tests will be displayed onto an external monitor and the overall prognosis will be given. Once we prove that this can be done, more tests can be implemented into the system that will both enhance the results for ruby, but can be applied to other gems.

2.1.1 Motivation

Much of the current crystal characterization methods require years, even decades of experience to have trustworthy conclusions. With every type of gem, there are several methods crystallographers must choose from that all require different equipment and levels of expertise. This project seeks to prove that an all-in-one system can be created, with ruby chosen as our sample gem. With every ruby that can be found online, implementing a certified test that this system produces will ensure authentication of any highly priced “ruby” on the internet. It will remove the chances of any ruby being dyed quartz or garnet, provided that this test is conducted. Gem collectors as well as smaller businesses getting into the gem cutting industry will be able to rely on this system to ensure that they aren’t getting scammed. In addition, if this device is made available at any reputable jeweler, it will ensure normal people can use this system at a cheaper cost than taking it to an expert to have it reviewed. Collectors will be able to purchase this device and not get scammed by many of the workarounds that exist today.

2.2 Objectives

Goals

- Build a ruby characterization system that implements both fluorescence and crystal structure tests.

Objectives

- Build a spectrometer that operates within the visible range.
  - Will read fluorescence and impurity spectra.
- Develop a dichroscope that will measure the crystalline properties of the ruby and implement the results into the spectrometer.
- Design a system that will orient the ruby in three different directions while illuminating the sample with an LED.

- Develop software that will analyze the data provided by the above tests and display the results to the user.

2.2.1 Function of Project
The function of this project is to be able to determine the spectra of a ruby given different tests. It will be in an enclosed system to avoid any external influences. It will read the data from the spectrometer after the fluorescence and dichroism tests and display it to the user, while saying whether the sample passed or failed the tests. This will allow users to determine whether the ruby is real, that is, made of aluminum doped with chromium to make red corundum, in order to avoid fake imitations of garnet or dyed quartz and to know whether the money they're spending on the gem is going towards what they think it is.

2.2.2 Specifications
Table 2.2.1 REID Specifications List

Power Consumption	TBD
Green LED Wavelength	550 nm
White LED Wavelength	400-650 nm
Minimum Ruby Size	TBD
Maximum Ruby Size	TBD
Operating Temperature	TBD

2.2.3 Requirements
Our project combines electrical, optical, and software systems to create a multi-functional characterization system within an enclosed system. The first part of the optical design will use a spectrometer comprising 2 lenses, a diffraction grating, a fiber, and a photodetector. A spectrometer is able to give a much more accurate reading of emission wavelength than the objective analysis of the human eye. The lens at the input end of the fiber will be of a much higher power than the ones in the system in order to minimize the beam size that enters the fiber to ensure minimal light losses. A fiber will be implemented rather than free space propagation to ensure minimal light loss as well as flexibility in where the optical system is located. The implementation of these separate optical components will ensure as accurate of readings as possible. Once analysis of the fluorescence test occurs, the peaks in the spectra will be assessed to determine whether it passes the test.

The second part of the design will be the dichroscope and the collimating system to implement the output into the spectrometer. It will consist of two glass prisms, a calcite rhombus, four lenses, two mirrors, and a beam splitter. The glass prisms exist to ensure that light is guided into and out of the calcite most effectively. The calcite itself exhibits birefringence, and thus is used to separate out the different polarizations of incoming light for our analysis. These polarizations will be of different wavelengths, thus will be collimated via the lens system and directed to the spectrometer using the two mirrors. The beam splitter will be used to guide the light into the fiber that is used by the spectrometer while not interfering with the initial setup. Upon analysis of this spectrum, the different peaks will be reviewed to determine whether the test passes.

The second optical component requires readings from different angles, thus a rotation stage will be implemented. Three random orientations of the gem will be chosen to have the maximum chance of receiving accurate results. The results from this portion will be tested individually, and the individual successes or failures will be displayed rather than a single pass or fail. In addition, a minimum ruby size will need to be established to ensure maximum reliability in this optical system.

Two LEDs, one white and one green, will be implemented into the housing to enable the two optical components. The green LED will be to ensure the ruby fluoresces at the right spectra for the first test, while the white LED will be purely for illumination of the sample for the second test. These LEDs will not move and will be soldered into an in-house circuit that will be protected from both the internal components and external (ambient) conditions of the system.

The primary programming language this project will involve is Python, its considerable amount of search libraries as well as the presence of third-party modules allows it to be flexible and an ideal option. It's ideal for prototypes due to its user-friendly data structures and thus a fit for this proof-of-concept design that ideally be expanded upon in the future. It's portable across operating systems, which is incredibly handy for getting this system out to a diverse array of users.

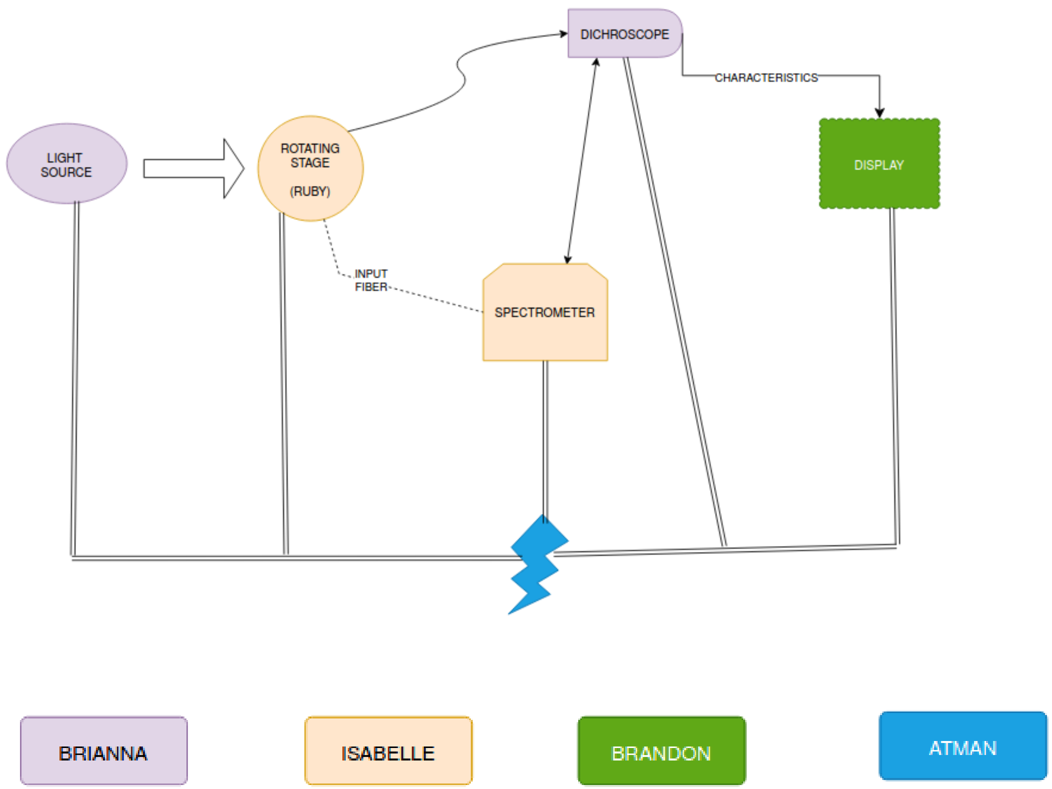
The housing of the system will be 3D printed and coated with a minimally-reflective paint to ensure the light from the LEDs has minimal impact on the spectrometer readings. This will impact the intensity of our readings, thus strong illuminators will be needed. The dimensions for the different components that will be exposed to the ruby will be considered and implemented into the system to ensure maximum tolerance (minimal wiggling) of the chosen components. The internal housing will be purely for the ruby exposure and data collection, and a second layer will be implemented to make room for both the optical and electrical components. It will need to have proper support within to ensure that any bumping or movement of the system will not impact the components within it. The supports will need to be removable so that proper design can be achieved within the housing without jeopardizing the structure and having minimal interference with the alignment of the optical setup or touching the electrical components.

In essence, the requirements of this project will give proper exposure to all of the aspects of being an engineer in today's world. It is essential for most devices today to have electrical, software, and optical components to ensure usability for as many people as possible and further integration as technology develops. Working on a team with diverse skills and backgrounds will give the slightest hint into what being an engineer in the modern world really entails.

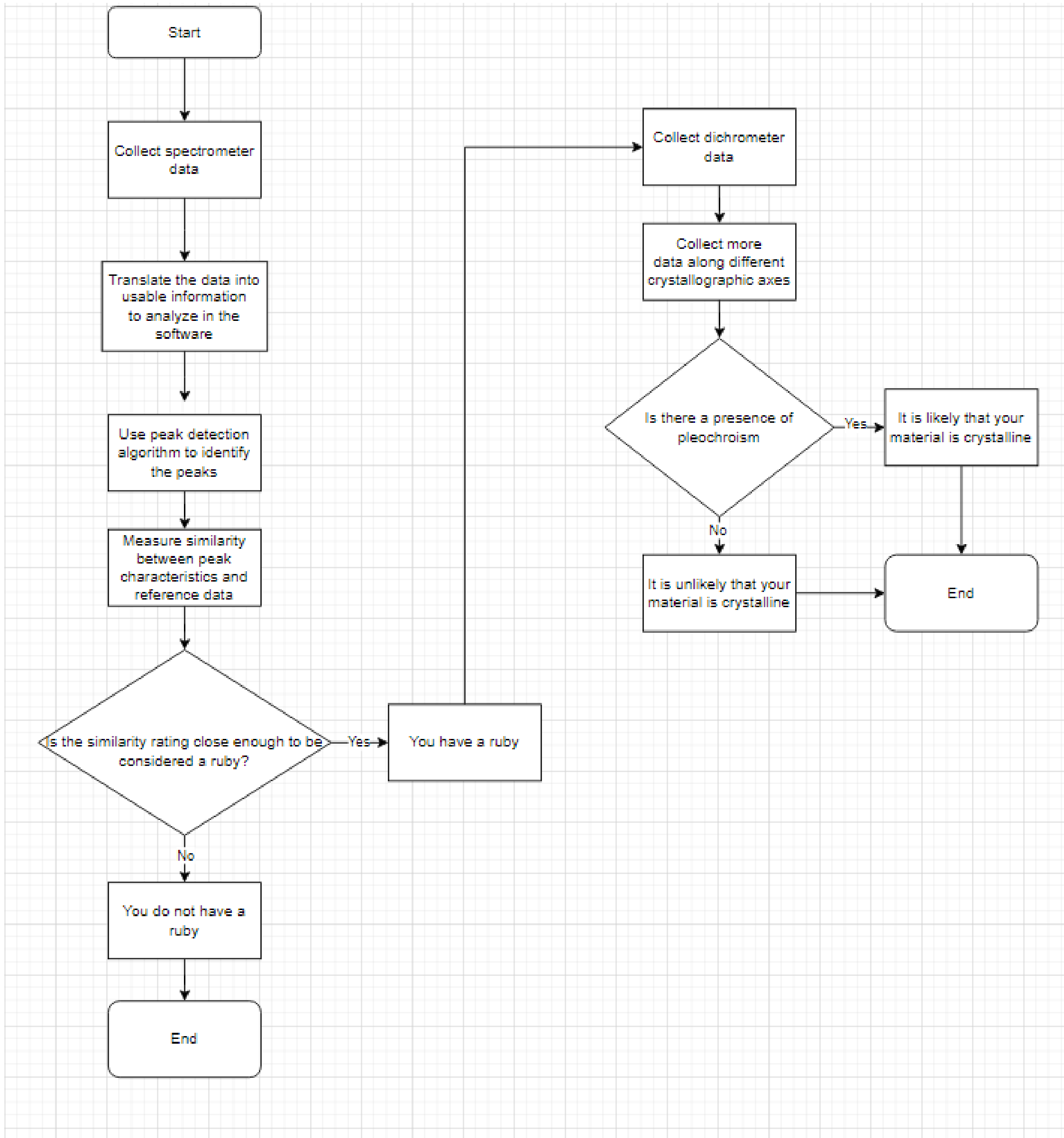
2.2.4 Hardware Block Diagram

Block Status as of September 15th, 2023:

- Each block is currently being researched/designed.
- No blocks have been purchased or acquired.
- No blocks have been completed.
- No prototypes have been made.



2.2.5 Software Flowchart



2.3 Marketing Requirements

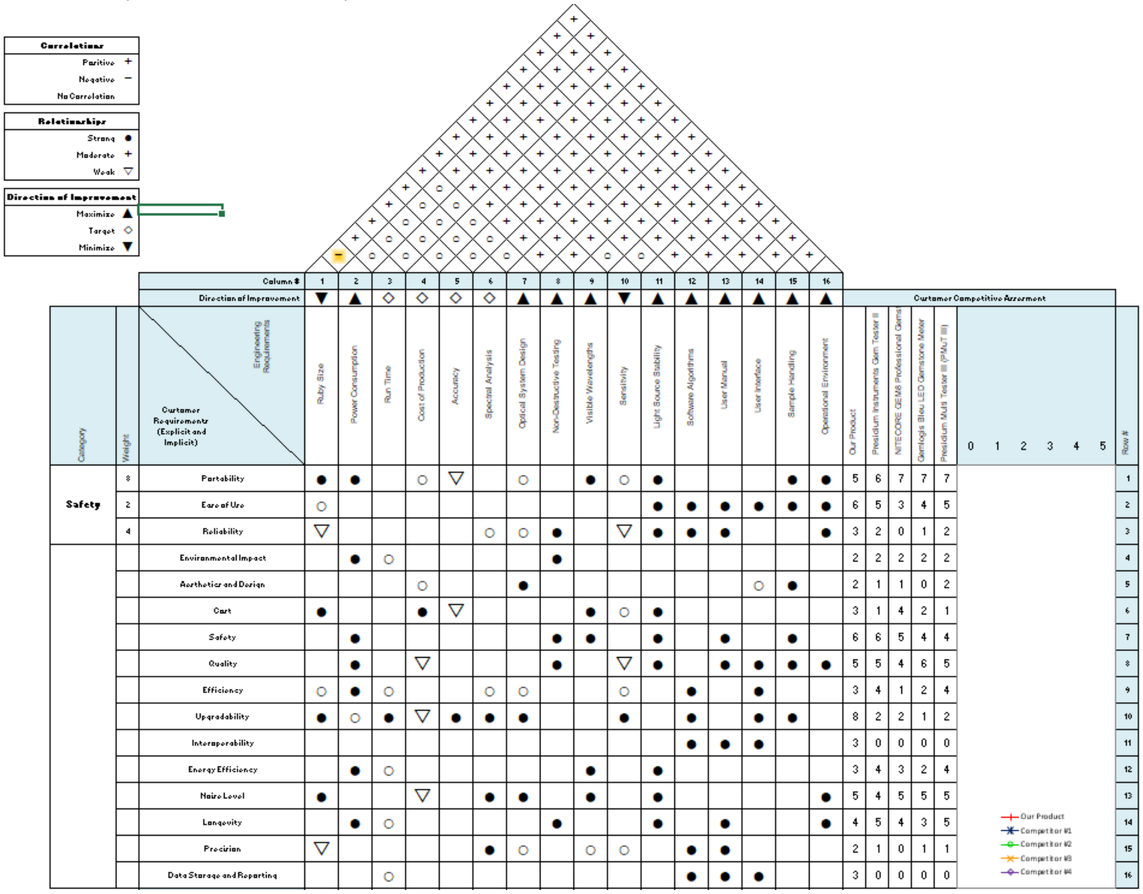
When designing technology of any kind, it's important to have a discussion about the marketability of that product. What goes into this is safety, the cost of production, the cost of the components, the time it takes to make the product, how easy it is to transport, and many other factors. We as engineers need to take all of these factors into consideration when making a product. The most important one is making the project as cost-effective as possible in every aspect while not jeopardizing reliability. The goal of this system is to make it available to collectors, artisans, or anyone who would want to ensure that their ruby is what they think, or were told, it is.

The usability of a product is imperative to its success on the market. It should be simple so that both expert and novice alike can utilize it with minimal troubleshooting. As this is meant to be placed in gem shops and available for public use, a necessary assumption is that the consumer will have little to no technical background and will not be able to understand the science behind the system. In addition, it will have to be easily transportable so that collectors can take it with them to auctions or suspicious jewelers. With this in mind, the most difficult part of the system will be placing the intended sample in the receptacle and understanding the required sample size. A simple sticker detailing these specifications can be used, and thus will enable a larger consumer base and encourage widespread use of the system.

In order to advertise this, we will have to choose an audience to market to and ensure we are catering our promotions to the best of our ability. Our intended client base are jewelers who may not have time to characterize every ruby that comes into their shop as well as collectors, who often get scammed at auctions. We will have to ensure that the general public can use this system for a small price and it can be a passive income for shop owners. People who own this product personally will want it to fit somewhere convenient and without much hassle in transportation so that they can take it to auctions. We plan to design this product on as small of a scale as possible while ensuring stability. Of course, the user cannot drop the system, but small jostles should not affect any components within. In addition, the form of media this is featured on will need to be considered to reach these audiences. Potential options are printed media, specialized browser ads, social media, sponsorships, partnerships, and many more. When considering this, the affordability and amount of reach of each advertisement will need to be analyzed and potentially tested to ensure optimal interest and purchases.

It goes without saying that a major objective is to make this system as cost effective as possible. Thus, methods such as Raman spectroscopy and X-Ray crystallography were avoided due to their large price points and potentially unsafe wavelengths. Visible wavelengths will be used due to the availability of economical components, such as the diffraction grating for visible wavelengths, less risk of eye damage should improper use of the system occur, and the lack of need of UV or IR filtering coatings on the optical components. LEDs are optimal light sources due to their low-cost and reliability in the modern world. It was decided to use a calcite dichroscope as opposed to a simple polarizing one because the price difference is not major and the calcite variant produces much more reliable results. The housing will be 3D printed due to its availability and cheap material.

2.4 Quality of House Analysis



Category	Weight	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Our Product	Presidium Instruments Gem Tester II	NITECORE GEM8 Professional Gems	Gemlogis Bleu LED Gemstone Meter	Presidium Multi Tester III (PMUT III)	Row #
		Direction of Improvement	▼	▲	◇	◇	◇	◇	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲						
		Customer Requirements (Explicit and Implicit) / Engineering Requirements	Ruby Size	Power Consumption	Run Time	Cost of Production	Accuracy	Spectral Analysis	Optical System Design	Non-Destructive Testing	Visible Wavelengths	Sensitivity	Light Source Stability	Software Algorithms	User Manual	User Interface	Sample Handling	Operational Environment						
Safety	8	Portability	●	●		○	▽		○		●	○	●				●	●	5	6	7	7	7	1
	2	Ease of Use	○										●	●	●	●	●	●	6	5	3	4	5	2
	4	Reliability	▽					○	○	●		▽	●	●	●			●	3	2	0	1	2	3
		Environmental Impact		●	○					●									2	2	2	2	2	4
		Aesthetics and Design				○			●							○	●		2	1	1	0	2	5
		Cost	●			●	▽				●	○	●						3	1	4	2	1	6
		Safety		●						●	●		●		●		●		6	6	5	4	4	7
		Quality		●		▽				●		▽	●		●	●	●	●	5	5	4	6	5	8
		Efficiency	○	●	○			○	○			○		●		●			3	4	1	2	4	9
		Upgradability	●	○	●	▽	●	●	●			●		●		●	●		8	2	2	1	2	10
		Interoperability												●	●	●			3	0	0	0	0	11
		Energy Efficiency		●	○						●		●						3	4	3	2	4	12
		Noise Level	●			▽		●	●		●		●					●	5	4	5	5	5	13
		Longevity		●	○					●			●		●			●	4	5	4	3	5	14
		Precision	▽					●	○		○	○		●	●				2	1	0	1	1	15
		Data Storage and Reporting			○									●	●	●			3	0	0	0	0	16

**This will be updated as the project develops and as more guidance is provided. Better image can be found [here](#).*

3 Research

3.1 Existing Similar Projects and Products

The current relevant technologies that exist for gem characterization typically serve one purpose or are complex and expensive. Those options will be explored as well as the single system that exists that can characterize whether a gem is real or not, but are not similar to this project. There are not many previous designs that exist that aim to achieve what this project will do.

3.1.1 Dichroscope Alternatives

London Dichroscope

There are two types of dichroscopes, one that uses calcite and another that uses simple polarizing filters, called the "London dichroscope". Both will produce a split image that represents any pleochroic colors that are present. When researching this, it was found that the simple polarizing method only allows for only one pleochroic color to be seen at a time. This is not optimal for this project's desired setup and would require more components that would consume more time and make results more difficult to achieve. In contrast, the calcite variant allows both colors to be viewed at the same time, hence the choice to implement this method that can easily be distinguished via spectroscopy.

Refractometer

The refractometer is another method that confirms the doubly refractive property of ruby. Rubies have a very specific refractive index that can be tested with this device, but requires a well-polished and flat facet to place on the surface of a prism in addition to a contact liquid between the respective refractive indices of the prism and the gem. Rubies are not always perfectly polished, and this would cause further limitations in the design of this product. In addition, the contact liquid would need to be constantly applied, and novices may damage optical components if the proper amount of liquid is not used or applied properly. Given all of these conditions, implementing a refractometer into this system would cause it to be less attractive to users without a fundamental understanding of the system. The dichroscope, in contrast, is a much simpler device to use with more straightforward and easily-understandable results.

Polarimeter

Similar to the London dichroscope, the polarimeter utilizes two polarizing lenses to analyze the internal structure of rubies. It requires the gem to be analyzed at various angles and positions. It's vertically oriented, with the two polarizers placed on either side of the sample. Beneath the lower polarizer is an achromatic light source that enables linearly polarized light to enter the sample and to shine upwards into the second polarizer. This top polarizer is rotated 90° in either direction, and upon light output it can be determined whether the ruby exhibits pleochroism. However, without a side-by-side comparison, it can be difficult to determine whether the gem actually exhibits pleochroism, hence the popularity of the dichroscope. In addition, this system would require more hardware in the system than what's already planned. Many times the polarimeter is used in conjunction with the dichroscope for further validation of the test. However, because of the lack of reliability in the human eye to tell separate wavelengths, with the implementation of more advanced optical analysis that our project aims to achieve, the use of the polarimeter can be wholly eliminated without compromising reliability.

3.1.2 Spectrometer Alternatives

Spectrophotometers

Spectrophotometers are optical tools made for measuring the amount of light a sample transmits or absorbs at various wavelengths. Their main objective is to measure how much light a substance absorbs or transmits, and this measurement is useful for many different purposes. Spectrophotometers can measure light from a variety of spectral ranges, including ultraviolet (UV), visible (Vis), and infrared (IR) light, depending on the model and the sample's absorption properties. These tools are necessary in many domains of science and industry where the quantitative examination of chemical compounds is crucial.

In disciplines like chemistry, biology, environmental science, and pharmaceuticals, spectrophotometers are widely used. They are used in molecular biology to quantify DNA and proteins, allowing for quick and accurate measurement of nucleic acid and protein quantities. Spectrophotometers are essential for quality control and research in many sectors because they are used in analytical chemistry to calculate the solute concentration in solutions. Additionally, environmental scientists frequently employ spectrophotometry to monitor water quality, gauge pollutant levels, and examine the chemical make-up of environmental samples. Spectrophotometers are tools used in pharmaceutical laboratories to assist in the formulation and quality control of pharmaceuticals and treatments, assuring uniformity and adherence to legal requirements. In many scientific and industrial applications, spectrophotometers are essential tools for quantitative analysis and quality assurance.

The optical instruments spectrometers and spectrophotometers are related yet have different uses and applications. Spectrometers are versatile instruments made to study the full electromagnetic spectrum and break it down into its individual wavelengths. They are commonly used to detect elements, compounds, and analyze the spectral characteristics of light sources in disciplines like astronomy, material science, and chemical analysis. Spectrophotometers, on the other hand, are specialist tools designed for measuring the absorption or transmission of light by a sample at particular wavelengths. They are essential for applications including DNA and protein quantification, environmental monitoring, and chemical concentration measurements in a variety of sectors because their main function is quantitative analysis. While both tools are used to study light and how it interacts with matter, spectrophotometers offer precise, quantitative data at particular wavelengths, whereas spectrometers give a comprehensive view of the spectrum. This allows for accurate concentration determination and quality control in analytical and biological assays.

Spectroradiometers

Spectroradiometers are specialized optical devices made for taking accurate readings of the spectral radiance, also known as irradiance, of light sources over a range of wavelengths. They are indispensable instruments for a variety of applications that call for precise characterization of light sources because their main function is to quantify the intensity of light at each wavelength in the spectrum. In areas like lighting design, remote sensing, and calibration, comprehensive spectral information from spectroradiometers is essential for comprehending and managing the spectral properties of light.

Spectroradiometers are used in many different fields where precise spectrum data is required. These tools are used in lighting design to gauge and assess the spectrum power distribution of man-made light sources, assisting in the development of excellent, cost-effective lighting systems for both indoor and outdoor settings. In order to quantify the spectral reflectance of surfaces on Earth or other planets and enable the study of vegetation, water bodies, and atmospheric conditions, spectroradiometers are also essential in remote sensing. Additionally, these tools are employed in the calibration and quality control of light sources, such as LEDs, lasers, and displays, to guarantee that they work consistently and dependably and adhere to predetermined industry standards. Overall, spectroradiometers are essential in applications that depend on precise spectral data to produce the best outcomes and scientific revelations.

Spectrometers and Spectroradiometers are optical devices with distinct but connected uses. Spectrometers are useful for detecting elements and compounds as well as for examining the spectral characteristics of light sources since they are made to examine and separate electromagnetic energy into its component wavelengths. The spectral brightness or irradiance of light sources across a range of wavelengths is carefully measured using spectroradiometers, which are specialist instruments. Spectrometers are frequently employed in disciplines like chemistry, astronomy, and material science because they provide qualitative information on the composition and features of substances. Contrarily, because spectroradiometers concentrate on quantitative information, they are essential for tasks like lighting design, remote sensing, and the calibration and quality control of light sources. While spectrometers and spectroradiometers both entail the study of light, they serve different purposes in different scientific and industrial contexts. Spectrometers provide a more comprehensive qualitative perspective of the spectrum, whereas spectroradiometers provide exact quantitative data.

Spectroscopes

Spectroscopes are straightforward optical instruments, frequently handheld, that are used for qualitative spectral analysis. Their main objective is to graphically represent the light spectrum so that observers may recognize the presence of particular spectral lines or bands in a sample. Spectroscopes are convenient tools for quick and basic qualitative analyses of the spectrum properties of diverse light sources because of their portability, affordability, and ease of use. Spectroscopes are useful teaching tools and can be useful for amateur astronomers, hobbyists, and basic science investigations even though they lack the precision and quantitative capabilities of more sophisticated spectrometers or spectrophotometers.

In order to introduce students and enthusiasts to the idea of spectroscopy and the behavior of light, spectroscopes are frequently employed in educational settings. They offer a quick and easy way to see the distinctive spectral lines or bands created by various light sources. The spectra of stars and other celestial objects can be observed and identified using spectroscopes by amateur astronomers and stargazers. Despite having fewer uses than more advanced spectroscopic instruments, spectroscopes are essential for promoting an awareness of spectral analysis and acting as a starting point for people who are curious about the intriguing field of spectroscopy.

While both spectrometers and spectroscopes are used to examine the spectral characteristics of light, their complexity, accuracy, and uses are very different. The intensity of light at various wavelengths can be precisely measured by spectrometers, which are sophisticated analytical equipment. For activities like identifying elements, compounds, and assessing spectrum properties, they are utilized in scientific research, industry, and fields including chemistry, astronomy, and material science. In contrast, spectroscopes are simpler, qualitative instruments that visually display spectra, primarily serving instructional and introductory purposes. While they lack the precision and quantitative capabilities of spectrometers, spectroscopes are important for exposing students and enthusiasts to the fundamental ideas of spectroscopy and are widely used by amateur astronomers to detect and identify celestial spectra.

Gas Chromatography-Mass Spectrometers (GC-MS)

Powerful analytical tools called gas chromatography-mass spectrometers (GC-MS) combine two different techniques to separate and identify the constituents of a complicated mixture. In the first step, gas chromatography (GC), the sample is vaporized and sent through a chromatographic column to separate it into its constituent parts. Based on their chemical characteristics and interactions with the column material, the mixture's components separate while being carried by a carrier gas. The separated chemicals are ionized by the eluted substances and measured by the mass-to-charge ratio of the resultant ions in the mass spectrometer (MS). The GC-MS system is an invaluable tool in areas including analytical chemistry, forensics, environmental investigation, and pharmaceutical research since it may enable extremely specific identification of particular compounds in a sample.

Forensic scientists frequently utilize GC-MS to analyze drugs, explosives, and trace evidence discovered at crime scenes. It is used in environmental research to monitor pesticide residues in food, analyze soil contamination, and detect and quantify pollutants in air and water. For drug analysis, quality assurance, and the identification of active ingredients in pharmaceuticals, the pharmaceutical sector relies on GC-MS. Analyzing food product composition and finding pollutants are both utilized in food safety. The identification of volatile organic compounds is aided in research and development by GC-MS, making it an essential tool in fields like organic synthesis and natural product analysis. In many different domains where precise and highly specific compound identification is crucial, GC-MS is unavoidable.

Both spectrometers and GC-MS devices are essential in analytical chemistry, although their capabilities and main uses are different. Spectrometers are adaptable instruments made to evaluate the full electromagnetic spectrum. They are frequently used to detect elements and compounds as well as to investigate the spectral characteristics of light.

They offer qualitative data, providing perceptions on the make-up and traits of substances. The exact and extremely specific component identification in complicated mixtures is provided by GC-MS devices, which combine gas chromatography and mass spectrometry. They provide quantitative data and are highly effective in industries that require precise compound identification, including forensic investigations, environmental monitoring, and pharmaceutical research. GC-MS instruments are crucial for applications requiring precise compound identification and concentration determination since they are specialized for quantitative and particular analysis, in contrast to spectrometers, which have a broader, qualitative focus.

Spectrometers are adaptable instruments that have significantly altered our understanding of the physical and chemical properties of the universe. They are used in a variety of fields, including chemistry, astronomy, and environmental science. Understanding the basics regulating spectrometer operation, their wide range of applications, and the essential components involved in their manufacture can help us appreciate the critical role these devices play in advancing scientific knowledge.

3.1.3 General Alternatives

Gem Testers

There is a singular device that claims to be the industry's most trusted colored gemstone tester. The Gem Tester II differs from this project in that it tests more than one gem type, ranging from glass to diamond, rubies, emeralds, and many more imitations. It's compact and portable. It doesn't involve any optical components and solely uses thermal conductivity to determine the gemstone's quality. The company that makes it is called Presidium, and they have made two versions of this type of test. However, the thermal conductivity test has been shown to have workarounds that have even been done during live gem shows or auctions. This renders this system, with only one function, unreliable. They also feature a handheld version, which can also be bypassed.

The Presidium Multi Tester III is a device that is closer to what our project aims to achieve, however it only identifies colorless diamonds and moissanites. It does not aim to achieve the same with rubies. It does both thermal and electrical conductivity tests, however it cannot be applied to rubies. It is similar to this project only in that it is multifunctional.

With all alternative options considered, it has been deemed that this project is the first of its kind in the gemology of rubies. The dichroscope is the most cost-effective, layman friendly, and reliable method of determining the pleochroic properties of rubies. In addition, fluorescence tests are incredibly difficult to bypass and thus has been chosen as another primary test in this project design.

3.2 Relevant Technologies

3.2.1 Software

3.2.1.1 Microcontroller/Arduino Software

General Use

The use of microcontroller devices such as Arduino and Raspberry Pi's are often used when creating a spectrometer, with good reason too. Arduino and Raspberry Pi code can be crucial in managing many aspects which include light sources, diffraction gratings, and detectors. If these systems are used the software would be beneficial and essential for tasks such as taking measurements, handling any of the signals from the device, or transmitting the data to another device for further analysis.

Effectiveness for Gemstone Analysis

The suitability of this software for gemstone analysis hinges on the finer details of the project's requirements. When it comes to basic spectrometer operations, this software is a reliable option, adequately serving the purpose. The software efficiently handles straightforward tasks such as capturing simple absorption spectra, this makes it a valuable tool for routine gemstone analysis. However, for more demanding and advanced gemstone analysis techniques, which require the identification of distinct gemstone types based on intricate spectral signatures and extracting highly detailed information from the sample, it may be necessary to enhance the capabilities of the software by integrating advanced data processing tools when computing this information.

In these more complex cases, advanced data processing tools can significantly enhance the depth and precision of your gemstone analysis. These supplementary software options are more adept at handling complex data manipulation, spectral deconvolution, and multivariate analysis, allowing you to extract more detailed information from the spectra. These tools also allow users to perform sophisticated pattern recognition and statistical analyses, which would be vital when trying to identify and characterize gemstone materials with precision.

Moreover, the incorporation of advanced data processing tools can open the door to in-depth research and comprehensive gemological studies, enabling you to explore intricate gemstone properties, trace their origins, detect treatments or enhancements, and gain a comprehensive understanding of the gemological world. While the basic spectrometer software remains essential for routine tasks, the integration of advanced data processing tools broadens your capabilities and enables you to delve deeper into the multifaceted realm of gemstone analysis.

3.2.1.2 LabVIEW

General Use

LabVIEW is a versatile graphical programming environment designed for the precise control of instruments and the acquisition of data.

One of the standout features of LabVIEW lies in its remarkable adaptability and compatibility with an extensive array of hardware components. This inherent versatility means that LabVIEW is exceptionally well-suited for the development of spectrometer setups that can be customized to meet even the most intricate and specialized requirements. This broad hardware support not only ensures that a diverse range of sensors, detectors, light sources, and other spectrometer components can be seamlessly integrated but also enables the creation of spectrometer systems that can address the unique needs of specific applications.

LabVIEW extends its capabilities into the realm of user interface design. With its innate support for creating tailored graphical user interfaces (GUIs), it becomes possible to craft user-friendly and highly intuitive front-end applications. These GUIs serve as the connecting tool through which operators can interact with the spectrometer, offering a rich and catered user experience that enhances the control, monitoring, and analysis of the spectrometric data.

LabVIEW is a software platform that can be utilized by those working on the development of custom spectrometers. The unique blend of visual programming, hardware compatibility, and user interface design capabilities allows engineers, researchers, and scientists to create spectrometer solutions that are both functional and accessible. In the evolving landscape of spectrometry, LabVIEW can be a valuable tool when aiming for accurate and insightful data analysis.

Effectiveness for Gemstone Analysis

LabVIEW excels when you want to create a user-friendly interface for your spectrometer. Its graphical nature simplifies the creation of control interfaces and data visualization tools. For gemstone analysis, where precise control and real-time data presentation are vital, LabVIEW can be highly effective. You can develop custom GUIs that allow users to control the spectrometer, select gemstone types, and view spectral data in real-time. Moreover, LabVIEW offers advanced data analysis capabilities, including Fourier transformation, peak identification, and spectral comparison, which are useful for gemstone analysis.

LabVIEW emerges as an outstanding choice when your objective is to craft an interface for your spectrometer that melds user-friendliness with functionality. At its core, LabVIEW embraces a graphical programming system, making the process of constructing control interfaces and developing data visualization tools a more simplified experience.

In terms of gemstone analysis, where precision and real-time data presentation are important when trying to determine success, LabVIEW performs well as a software tool. Its ability to facilitate the design of custom GUIs introduces many possibilities. These tailor-made GUIs serve as the basis in which users can have control over the spectrometer, allowing them to make selections such as identifying specific gemstone types and viewing the spectral data in real-time. The real-time data presentation becomes a valuable asset in the gemstone analysis process, allowing gemologists and researchers to assess gemstone properties quickly.

3.2.1.3 Python with Libraries

General Use

Python stands as an incredibly powerful and adaptable programming language, known for its widespread utilization across many scientific and engineering domains. Its full capabilities are realized when utilizing many of its specialized libraries, including but not limited to numpy, matplotlib, and scipy. All of the tools and libraries in addition to the base version of Python make it into an all-encompassing toolkit, perfect for taking the reins of numerous projects including DIY spectrometers, enabling the acquisition of spectral data, and masterfully conducting in-depth data analysis and visualization.

Python and its extensive libraries form the backbone of a versatile and highly customizable solution for spectrometer control and data management. In the realm of DIY spectrometry, the ability to utilize Python's programming capabilities brings forth numerous possibilities. By leveraging this language in along with the aforementioned libraries, users can design and implement control systems that govern the spectrometer's various components, whether it be the illumination source, grating, or detector, all with the ability to tailor the controls to the specific needs of the project.

One of Python's standout qualities is its aptitude for data handling and analysis, and this is where the numpy and scipy libraries step in. These libraries provide a wide set of functions and tools for numerical and scientific computing. The numpy library offers a robust framework for efficient handling of multi-dimensional arrays and matrices, this is essential for storing and manipulating spectral data. Meanwhile, scipy enhances Python's capabilities by providing a wide array of specialized functions that makes it an ideal tool for many scientific and engineering applications. It has capabilities for signal processing, optimization, statistics, and more, allowing users to have most, if not all, that they may need to process and analyze spectral data with precision.

In addition, another library, matplotlib, adds more capabilities in terms of data visualization. It has many options of plotting tools and functions and allows users to craft captivating and informative graphical representations of the spectral data. This feature is significant for analyzing the actual spectra and also for conveying results to peers, students, or stakeholders in a well displayed format.

Using an overall view on spectrometry, Python, in tandem with libraries like numpy, matplotlib, and scipy, assumes the role of a powerful and versatile tool that’s indispensable. Its ability to facilitate DIY spectrometer control, data collection, analysis, and visualization will most likely provide all that is needed for any scientific or engineering purpose.

Effectiveness for Gemstone Analysis

One of Python's standout qualities is its adaptability. Because it is so open-ended and customizable, users are able to create tailored scripts and applications that should be able to work through the entire gemstone analysis process very efficiently. The first step of this whole process would be the acquisition of spectral data. Python excels in enabling users to design scripts that can efficiently collect and store this valuable data for further use in the process.

Python's power is way more than just data collection. Preprocessing, another crucial step in gemstone analysis, can be conducted through the use of Python scripts. We will be able to implement preprocessing algorithms, refining and conditioning spectral data to create a more accurate analysis.

Because of Python's capabilities and ability to be versatile we can continue to use it for even more than data preparation. We can also work with advanced analysis techniques and be able to implement algorithms that cater to the unique demands of gemstone analysis. Users can harness the libraries available in Python's ecosystem to create algorithms that precisely match acquired spectra with established reference data, further helping in the authentication and classification of gemstones.

Furthermore, Python can efficiently take on the challenging task of absorption peak identification, where it enables the development of algorithms that pinpoint characteristic features within the spectra. This capability is crucial for gemstone analysis, as these readings are some of the most important information when trying to read the data and it aids in the differentiation of gem types based on their distinctive spectral signatures.

In conclusion, Python emerges as an excellent choice for gemstone analysis when considering a DIY spectrometer. Its multifaceted capabilities, rich ecosystem of scientific libraries, and adaptability ensure that it makes the data acquisition and preprocessing phases as easy and streamlined as they could be and also offers an expansive toolkit for advanced analysis techniques. The language's capabilities elevate it to the forefront of gemstone analysis, enabling enthusiasts, gemologists, and researchers to further their studies with enhanced precision, efficiency, and depth.

3.2.1.4 Custom Software

General Use

Custom software development involves creating software from the ground up, tailored specifically to your spectrometer's design and gemstone analysis requirements. This approach offers maximum flexibility but requires significant programming expertise and time.

Effectiveness for Gemstone Analysis

Custom software can be highly effective for gemstone analysis, especially when you have precise control requirements or need to implement unique analysis algorithms. You have full control over software functionality, enabling you to design workflows that match your specific gemstone analysis needs. For instance, you can develop algorithms for identifying gem types based on spectral fingerprints, integrating external databases, and performing statistical analysis. However, this approach demands a substantial development effort and expertise in areas like signal processing and data analysis.

3.2.1.5 Spectroscopy Software Libraries

General Use

Spectroscopy libraries, such as `python-seabreeze` and `SpectraGryph`, provide pre-built tools for spectrometer control and spectral data analysis. These libraries simplify the software development process by offering standardized functions and classes for spectrometer communication and data processing.

Effectiveness for Gemstone Analysis

Using spectroscopy libraries can be highly effective. They offer a balance between flexibility and ease of use, making them suitable for various spectrometer setups and gemstone analysis tasks. You can leverage these libraries to quickly build software for acquiring and preprocessing spectral data. For gemstone analysis, you may use spectral libraries to implement methods like peak identification, absorbance calculation, and gemstone identification based on known spectral signatures.

3.2.1.6 GUI Frameworks

General Use

GUI frameworks like PyQt, Tkinter, and others allow you to create user-friendly interfaces for controlling the spectrometer and visualizing spectral data. These interfaces enhance the user experience by providing intuitive control and real-time data presentation.

Effectiveness for Gemstone Analysis

GUI frameworks are effective when you want to provide a user-friendly interface for your spectrometer, which is valuable in gemstone analysis applications. You can design interfaces that allow users to select gemstone types, initiate measurements, and view spectral data in a user-friendly format. These interfaces can also include features like real-time plotting, data export, and integration with external databases for gemstone identification. The choice of GUI framework depends on your programming skills and platform preferences.

3.2.1.7 Open-source Spectrometer Software

General Use

Open-source spectrometer software projects are often developed collaboratively by the scientific community. They may provide complete or partial solutions for spectrometer control and data analysis. These projects can serve as valuable resources for DIY spectrometer builders.

Effectiveness for Gemstone Analysis

If you find an open-source project that aligns with your DIY spectrometer's design and objectives, it can be highly effective. Open-source solutions can save you substantial development time and provide well-tested and optimized code for spectrometer control and data analysis. You may need to customize the software to meet specific gemstone analysis requirements, such as integrating spectral databases or implementing custom analysis algorithms.

In conclusion, the choice of software for your DIY spectrometer for gemstone analysis should align with your specific goals, programming skills, and project complexity. Python offers a versatile and accessible option with a wide range of libraries. LabVIEW is excellent for creating user-friendly interfaces. Custom software provides maximum flexibility but requires significant effort. Spectroscopy libraries and open-source projects offer a balance between ease of use and flexibility, making them suitable for various spectrometer setups and gemstone analysis tasks. GUI frameworks enhance user interactions, which can be valuable in gemstone analysis applications. Consider your priorities and constraints when selecting the best software for your DIY gemstone analysis spectrometer.

3.2.2 Optical Components

3.2.2.1 Spectrometer

Spectrometers are essential tools in various scientific disciplines, enabling us to analyze and understand the properties of light and matter. This paper explores the working principles, applications, construction, and a comparison with similar tools to shed light on the significance of spectrometers in modern science.

Spectrometers are tools used to separate and then measure the different properties of light, allowing us to obtain valuable information about the structure, properties and composition of various substances. With the assistance of spectrometers, scientists from several disciplines may examine how light interacts with different matters to determine the composition and characteristics of that material. In order to obtain useful information about the sample being investigated, they function according to the fundamental principles of light dispersion and a number of measurement techniques.

How Spectrometers Work

Spectrometers are an essential tool for various scientific studies and a variety of sectors because they make it possible to characterize light and analyze a considerable amount of detail of each material. They work by utilizing several measurement techniques and the laws of light dispersion, giving researchers insight into the make-up, structure, and characteristics of substances.

Spectra

Spectroscopy is a scientific tool that is used for understanding the properties of different materials and electromagnetic radiation. The three primary forms of a spectra that have been researched extensively and used often are the Emission spectra, absorption spectra and the continuous spectra. Each spectra has a specific use and provides unique information on the makeup of atoms, molecules and celestial objects. These spectras can be seen in Figure 1.

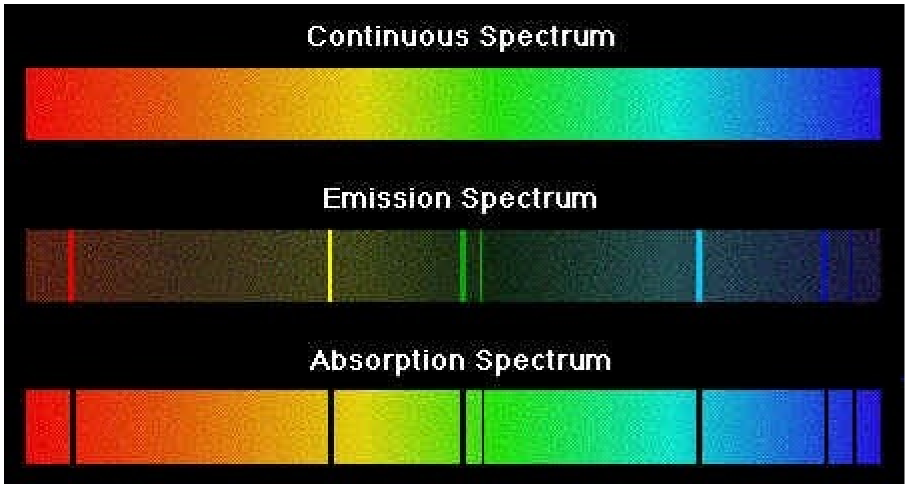


Figure 1 Three spectrums, Continuous, Emission, and Absorptions

The emission spectra is produced when atoms or molecules release energy in the form of electromagnetic radiation. This occurs when an excited electron in an atom or molecule reverts to a lower energy state, this is called energy release. The light that is illuminated has distinct sharp lines at the different wavelengths that are particular to the element or molecule that is being presented. Various applications like chemical analysis and the elemental makeup of stars and other celestial bodies utilities the emission spectra.

With respect to the emission spectra, the absorption spectra are produced when atoms or molecules absorb specific wavelengths of electromagnetic radiation. This absorption occurs as photons with specific energies are absorbed, advancing electrons in the ground state to higher energy levels. Where the absorbed wavelengths are not present, the spectrum as a result shows dark lines or bands. The study of the interstellar medium and estimating the concentration of specific elements or compounds both benefit from the use of absorption spectra to determine the make-up of substances in a sample.

Lastly, for the continuous spectra, the electromagnetic radiation is distributed uniformly and smoothly throughout a wide range of wavelengths. They don't have any distinct bands or lines that are shown in the emission and the absorption spectra. Blackbody radiation is commonly connected to the continuous spectra, this is when all potential wavelengths are present due to the thermal motion of particles. This is used to comprehend the temperature and make-up of astronomical objects, such as stars and galaxies, they are crucial.

The continuous spectrum results from the interaction of heat radiation with matter. While emission and absorption spectrums are created by interactions between matter and electromagnetic radiation. The absorption spectrum shows dark lines or bands at the same wavelengths, whereas the emission spectrum shows recognizable lines or bands that correspond to particular elements or molecules. The continuous spectrum lacks these particular characteristics. While the continuous spectrum is used to estimate temperature and composition, emission and absorption spectra are used to identify different elements, compounds, and even analyze celestial objects. The continuous spectrum offers details on temperature and composition, while the emission spectra illustrates the energy transitions of excited electrons, absorption spectra display the wavelengths that are absorbed.

For scientists in many different fields, continuous, emission, and absorption spectra are invaluable tools. While the continuous spectrum reveals information about temperature and composition, emission and absorption spectra provide insights into the energy levels of atoms and molecules. It improves our knowledge on the physical cosmos and beyond to comprehend the principles and uses of these three spectrums.

Dispersion of Light

In spectrometry, light dispersion is a crucial phenomenon. For the examination of spectral data, it involves the division of light into its individual colors or wavelengths. This dispersion happens when distinct wavelengths of light travel through a material, usually a prism or a diffraction grating, with varying refractive indices.

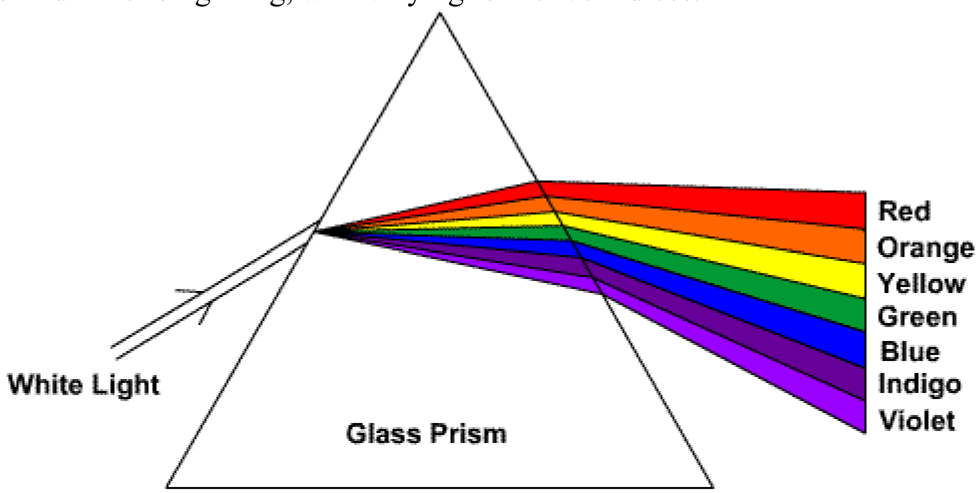


Figure 2 Shows the white light goes into a prism and splits into the various wavelengths.

White light, which is made up of all the hues that are visible, enters a spectrometer and undergoes dispersion, which causes a continuous spectrum from red to violet to form. This spectrum, which includes each of the many colors that make up white light, is frequently referred to as a "rainbow" spectrum. The wavelength of each hue determines how much it bends (or disperses), with shorter wavelengths bending more than longer ones. Numerous spectrometric measurement techniques are built on this dispersion.

Measurement Techniques

Spectrometers use a variety of measurement methods to learn more about a sample. The technique picked depends on the analysis's particular goals. Here are a few typical measurement methods for spectrometers:

1. Emission Spectroscopy: Emission spectroscopy is examining the light wavelengths released by an energized sample. The investigation of atomic and molecular species makes use of this technology particularly well. An atom or molecule passes through electronic transitions and emits recognizable light

wavelengths when it absorbs energy. Emission spectroscopy is frequently used in flame testing, element identification, and chemical reaction monitoring.

2. Absorption Spectroscopy: A spectrometer is used to gauge how much light is absorbed by a sample at particular wavelengths. The spectrometer measures the intensity of transmitted light after exposing the sample to a variety of light wavelengths. The composition and concentration of the sample can be inferred from variations in intensity at particular wavelengths.
3. Fluorescence Spectroscopy: When a sample is exposed to light, fluorescence spectroscopy is used to examine the fluorescence that is produced. Fluorophores are molecules that absorb light at one wavelength and then emit it at a longer wavelength. Environmental monitoring, drug discovery, and medicinal research all frequently employ this method.
4. Raman spectroscopy is a non-destructive method for gathering data on the rotations and vibrations of molecules. It entails examining the variations in frequency between the incident and dispersed light. In forensic science, pharmacological research, and material analysis, Raman spectroscopy is used.
5. Mass Spectrometry is a potent method that includes ionizing molecules and determining the mass-to-charge ratios of the ions. This technique is commonly used in chemistry, proteomics, and environmental investigation to ascertain the molecular weight, structure, and content of molecules.

In order to collect data about a sample, spectrometers split light into its individual hues and perform several measuring processes. Scientists use spectrometers to examine the composition, structure, and properties of materials in a non-destructive and highly informative way, whether by absorption, emission, fluorescence, or Raman techniques. These devices offer priceless insights into the universe of matter and are essential tools in domains ranging from chemistry and physics to environmental research and astronomy.

Applications

Spectrometers are versatile tools with uses in a variety of scientific disciplines. Spectrometers are utilized in three important disciplines: chemical analysis, astronomy, and environmental monitoring. Multiple applications show the instrument's value in advancing knowledge and solving pressing problems in various fields.

Chemical Analysis

Spectrometers are widely used in chemistry to identify and quantify the composition of substances. Techniques like UV-Vis spectroscopy and infrared spectroscopy are invaluable in this regard. In order to identify unidentified substances, spectrometers like infrared (IR) and mass spectrometers are essential. While IR spectrometers offer details about the functional groups found in organic molecules, mass spectrometry is utilized to ascertain the molecular weight and chemical structure of compounds. Quantitative analysis uses spectrometers to estimate the concentration of particular chemicals in a sample. For example, UV-Vis spectrophotometry is frequently used to calculate the concentration of ions, molecules, or other substances in solution. This has uses in food testing, environmental analysis, and pharmaceuticals. Chemical professionals can comprehend the three-dimensional structure of molecules with the aid of Nuclear

Magnetic Resonance (NMR) spectrometers. NMR is essential for studying the characteristics and behavior of various molecules, which enables research into drug discovery, materials science, and biochemistry.

Astronomy

In astronomy, spectrometers help scientists determine the composition, temperature, and motion of celestial objects. Tools like spectrographs are essential for studying the light emitted or absorbed by stars, galaxies, and other cosmic entities. Astronomers use spectroscopy to examine the light that stars and other celestial bodies release. Astronomers are able to determine the chemical makeup, temperature, and radial velocity of stars and galaxies using spectrometers, such as the spectrographs on board the Hubble Space Telescope. One important tool for describing exoplanets is spectroscopy. It aids in the detection of specific compounds, such methane or water, in the atmospheres of exoplanets. The knowledge acquired aids in the search for planets that may support life. The redshift of distant galaxies may only be ascertained with the aid of spectrometers. Understanding the universe's expansion and the development of celestial objects depends on this.

Environmental Monitoring

Spectrometers play a crucial role in environmental science by analyzing pollutants, monitoring atmospheric composition, and studying climate change through tools like spectroradiometers and lidar systems. Spectrometers, in particular infrared gas analyzers, are used in environmental monitoring to quantify the concentration of pollutants in the atmosphere. These tools are used in climate research because they can identify greenhouse gasses like carbon dioxide and methane. Water quality is evaluated using UV-Vis spectrophotometry and fluorescence spectrometry to measure factors including chemical oxygen demand (COD), turbidity, and the presence of contaminants such as heavy metals and organic pollutants. NIR spectrometers are used to examine the content and quality of soil. Spectrometers help to optimize agricultural methods and manage soil resources by measuring variables including nutrient content, pH, and organic matter.

Ruby Fluorescence Spectra

Ruby exhibits a red (694 nm) fluorescence spectra under long wavelengths. Specifically, ruby is excited within three absorption bands: 250, 410, and 550 nm. The pumping wavelengths excite the chromium ions and cause them to fluoresce. The lifetime of this excitation is short, only up to 50 ns. The ion then relaxes and makes its transition back to its stable state. This short excitation period is enough to allow for detection of this fluorescence spectra, thus the spectrometer will be implemented.

3.2.2.3 Dichroscope

When investigating methods of gem characterization, the dichroscope was one of the main tools in a gemologist’s arsenal. In order to verify the quintessential trigonal crystal structure of ruby, versus the hexagonal structure of quartz or cube-based garnet that do not exhibit pleochroism, this device may be used.

Dichroscopes operate on the concept of pleochroism, the general term for dichroism and trichroism, and it can only be observed in colored and doubly refracting crystals. Different crystal structures will exhibit different absorption and reflection wavelengths that are imperative in deciphering whether the crystal is real or fake. The readings of a dichroscope show these differing wavelengths plainly, and thus make it easy to determine to a novice gemologist or otherwise inexperienced layman whether the ruby has the proper qualities. The fundamentals of birefringence are essential in understanding why the dichroscope is so effective.

The dichroscope is a small instrument, able to fit into one's pocket. It can be used to test transparent crystals when used with a light source. The gem is first illuminated with an incoherent, achromatic light source and the viewing end of the dichroscope is placed as close as possible to the gem's surface. From there, the light enters the first aperture (a pinhole), is guided through a glass prism into calcite where the two wavelengths are separated, leaves the calcite and is once again guided by a glass prism into another pinhole, focused through a lens, and shone through two polarizers of opposing orientations. The two polarizing lenses will show the colors of the two wavelengths, and thus the structure of the crystal can be determined.

Birefringence and Calcite

When investigating the dichroscope, the reason as to why the inclusion of calcite ($CaCO_3$) makes the dichroscope more effective was explored. Calcite, in this application, is colorless or white when pure. It is number 3 on the Mohs hardness scale, thus can be scratched by a knife. When light passes through this mineral, it splits into two rays that travel at different speeds in different directions with different polarizations. This is called birefringence, and oftentimes can be observed with the naked eye. A clearer image of this can be seen in the diagram below.

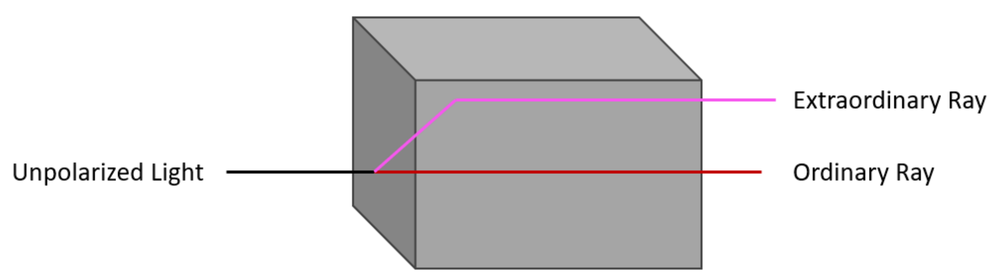


Figure 3: Ray representation through calcite.

Calcite has a rhombohedral structure and often shows hexagonal crystals. It is an anisotropic material, meaning different values are obtained when probing specimens from several directions despite it being the same material. Because it is anisotropic, it has a non-equivalent crystallographic axis and electromagnetic waves (light) that enter the crystal experience different refractive indices in different directions. EM waves first enter with the same velocity, but when interacting with the optical axis they are separated into two distinct rays.

Electromagnetic waves propagate through space with oscillating electrical and magnetic components that are oriented perpendicularly to each other and to the direction of propagation. Visible light is composed of both of these components, thus when interacting with a material the velocity of these waves is highly dependent on the electrical conductivity of the material. When traveling through the crystal, EM waves must interact with the electric fields of the atoms within the material, thus their speed is impacted.

The ordinary ray is the ray that follows the typical laws of refraction; it travels with the same velocity in all orientations through the crystal. The extraordinary ray travels with a velocity that is highly dependent on the direction it travels through the crystal, thus the need of the sample being observed from different angles. If incident light is parallel to the optical axis, it is not separated into individual components and the light rays exiting the crystal have the same optical path lengths. If it is perpendicular, the ordinary and extraordinary rays still occur and experience different optical path lengths, but emerge from the same location.

Crystal Structures and Pleochroism

Pleochroism is the effect of variations in color that is dependent on the polarization direction of incident light. The polarization direction is dependent on the orientation of a material in the incident light path and is only possible to be viewed via anisotropic materials.

For a mineral to exhibit pleochroism, it must have a specific crystal structure in which different wavelengths of light are absorbed. The angle at which it is viewed will show these different colors. Recall that as in anisotropic materials, refractive index changes with direction. Because the refractive index is wavelength dependent, different wavelengths will be absorbed at different angles. Thus, pleochroism is able to be viewed. Tetragonal, trigonal, and hexagonal minerals exhibit what is known as dichroic properties, where they show two colors. Orthorhombic, monoclinic, and triclinic crystals are trichroic. Isometric minerals do not exhibit pleochroism.

Ruby Optical/Structural Properties

Rubies are a natural, inorganic mineral that have trigonal crystal structures. It ranges from orange-red to pink-ish or purplish red in color, and is a variety of corundum. In this specific case, ruby is red because the corundum is doped with chromium. It ranks 9.0 on the Mohs scale, second only to diamond and moissanite.

Corundum, the main component of ruby, is the crystalline form of aluminum oxide and can contain different traces of choice materials. These materials can come in the form of inclusions or dopants that change the color of the corundum. It typically comes in the more well-known forms of ruby or sapphire. It depends on the dopants.

Corundum has a trigonal crystal structure, its lattice containing oxygen atoms that form an imperfect hexagonal close packaging. Two thirds of the octahedral spots between these oxygen ions are inhabited by aluminum ions. This structure is often described as pseudohexagonal.

Trigonal crystal structures, also known as rhombohedral systems, are defined by a three-fold rotation axis; they're often generated by stretching a cube along its diagonal and forming the cubic crystal system. These components are located in reference to four axes, three of them are equal length with 120° intersections, the remaining one is perpendicular to the plane the other three are located on. The structure can be rotated 120° about the rotation axis and each face presented will be identical to the starting face. Minerals with trigonal crystal structures exhibit double refraction and have two different refractive indices for light of two different colors.

3.2.2.4 Light Emitting Diode

Light emitting diodes, otherwise known as LEDs, consist of a single p-n junction diode. The main driving force behind LEDs is electroluminescence. The simplified explanation of this phenomena is the process in which current flows through a semiconductor and light is emitted.

A semiconductor is made of a base material with an unoccupied conduction band/full valence band (e.g. Si, GaAs) that is doped with impurities (e.g. As, B) to create free electrons (n) or holes (p). When a voltage is applied, it allows these free electrons and holes to move and meet at where the p-type and n-type materials are connected, called a junction. When these electrons and holes combine, light is generated. When free electrons in the conduction band drop to the lower energy level of holes to fill these gaps, the excess energy is released in the form of a photon. The difference in the energy levels of the electron and lower energy level will determine the energy of the photon. The higher the energy of the photon, the greater the frequency of light (shorter wavelengths). Most semiconductors have a low band gap energy level, thus don't generate much light. LEDs have semiconductors specifically chosen so that the energy drop is much higher and the photon is able to be viewed. To achieve the right wavelength of light for different applications, the proper energy gap has to be chosen.

Illumination Spectrum and Intensity

For the purposes of this project a green and white LED will need to be used. Due to ruby excitation properties, an LED that emits at a wavelength of 550 nm will be selected. It will need to be of a high enough intensity to cause the ruby to fluoresce, and this quality will be experimented with or calculated. For the dichroscope measurements, a white light LED with no predetermined wavelength will be needed, as its main purpose is to simply generate reflections from the internal crystal structures of the ruby.

3.2.2.5 Beamsplitters

A beamsplitter is an optical component that splits the incident light into two separate beams, hence the term. The ratio between these two beams is predetermined depending on their application. There are many different types of beamsplitters, which will be explored further.

Beamsplitters come in the forms of cubes or plates. Cubes are formed using two right angle prisms, one of which has its hypotenuse coated according to the application, then they are cemented together along their respective hypotenuses. Plate beamsplitters are flat glass plates that are coated on the first side of the substrate and designed for a 45° angle of incidence. Most of these components have an anti-reflection coating on the opposite side to remove Fresnel reflections. There are several advantages and disadvantages to using cube or plate beamsplitters, detailed in the table below.

Type	Advantages	Disadvantages
Cube	● Simple 0° AOI Integration ● No beam shift ● Equal reflection and transmission optical path lengths ● Optical system path lengths shortened	● Heavy glass construction ● More material ● Difficult and more expensive to manufacture in larger sizes ● Difficult to mount into a 3D printed system
Plate	● Lightweight ● Inexpensive ● Easily able to be scaled in the manufacturing process ● Easily mounted in a 3D printed system	● Reflection and transmission optical path lengths are different ● Transmitted light experiences a beam shift ● 45° AOI will require additional alignment time

In addition to the forms, there are different coating options for beam splitters. Standard beamsplitters are best for a versatile range of applications where unpolarized light and polychromatic light sources are in play. They're very flexible in how they're used and would be ideal in applications such as this project.

Polarizing beamsplitters are used to split incident light into s and p-polarized beams. The reflected beam would be s-polarized and the transmitted beam would be p-polarized. It is possible for both beams to have an equal ratio, despite the often occurrence of weaker p-polarized light. This is useful for polarization separation applications.

Dichroic (not in relation to ruby crystalline properties) beamsplitters split light by wavelength. They are often used for laser beam combiners designed for pre-designated wavelengths or hot and cold mirror applications. This is the type of beamsplitter often used in fluorescence applications. However, it will not be necessary here as hot and cold mirrors are used for separating visible and infrared light, this project utilizes spectra entirely in the visible region.

Some beamsplitters have an extinction ratio, where the p-polarized light is not effectively prevented from reflecting back and light loss occurs. Beamsplitters are typically good at reflecting s-polarization but are not good at preventing p-polarization reflections. When s-polarized light interacts with the reflection surface, the electric field and the surface share the same plane. However, when p-polarized light hits this surface, it has components both in the surface plane and perpendicular to the surface. Thus, the reflected light is not free of p-polarization whereas the transmitted light will be.

For the purposes of this project, the ideal beamsplitter would have an equal ratio between reflection and transmission to account for both the fluorescence and pleochroic spectra that this project requires. Different variations of both cube and plate beamsplitters will be considered in the part selections portion of this paper.

3.2.2.6 Lenses

The operating principle of a lens is refraction, which can be described as when light passes through a material it changes direction based on both the constituent wavelengths of the light and the properties of the material. They are made of transparent substrates such as silica or BK7 that are optimized for minimal absorption at different wavelengths and typically have at least one curved surface. There are two main types of lenses that will be considered for this project, named convex and concave lenses. When looking for the lenses we have to ensure the F-#, effective focal length, and curvature all match.

Convex lenses get their name from the outward curve of the external surface. They can also be called positive lenses or converging lenses. This shape enables incoming parallel or collimated rays to be focused onto a single point, called the focal point. This focal point varies based on the severity of the curvature of both sides of the lens as well as the thickness. When diverging rays enter a convex lens that is placed to maximize light input and optimize focal length, the rays become collimated. These lenses are typically used in microscopes or telescopes.

Concave lenses are the opposite of convex lenses, they are designed to cause rays to diverge after passing through them. Their surfaces are curved inwards, and they are often called diverging lenses. These lenses have an odd way of calculating the focal point, as one would have to calculate this value on the input side of the lens. They can be used in reverse to magnify an image but are typically used in making small, high resolution images larger for projection purposes.

Pertaining to this project, magnification of the input light will be needed in order to focus properly into the fiber and thus into the spectrometer. Thus, convex lenses will primarily be used and will be selected in later portions of this paper.

3.2.2.7 Prisms

Prisms are optical components that are cut with precise angles and plane faces in order to effectively analyze, reflect, or refract light. Ordinary prisms can be used to separate light into its constituent wavelengths. Prisms are useful in their ability to be modeled as a system of plane mirrors, as they can bend or fold light to change image parity. Multiple mirrors would need to be used to accomplish the same output of a single prism.

Prisms achieve what mirrors aim to accomplish through a principle called internal reflection, where light that enters this element is reflected internally and exits through the other side of the prism. There are two main types of prisms, and each will be detailed and considered for this project.

The first type is dispersion prisms, whose primary goal is to split light into its constituent wavelengths. This property of prisms is dependent on the geometry, the angles at which the prism is cut, and the index dispersion curve, which is based on the index of refraction of the substrate. Different wavelengths will deviate at varying angles and thus will be split.

Deviation prisms are self-explanatory, they change the beam path in order to rotate the output image or displace it from its original axis. These deviations are usually done at pre-designated angles and will change based on desired applications.

For the purposes of this project, two deviation prisms will be used in order to help guide the light through a calcite rhombus. They will be selected later in the parts selection portion of this paper.

3.2.2.8 Mirrors

Optical mirrors are used to reflect light in order to “steer” the incoming beam in the desired direction. They can be curved or flat depending on whether the beam size will need to be maintained, expanded, or minimized. Curved mirrors act as “reflecting lenses”, as they too have a focal point that can be used for different applications. Mirrors can be coated with different materials in order to specialize them for different wavelength ranges and absorption parameters. Flat mirrors will be used for this project due to their ease of acquiring and simple implementation. Mirror selection will be done later in this paper.

3.2.2.9 Optical Fiber

For this project the utilization of an optical fiber is to transport the light that fluorescences from the ruby to the spectrometer. To select this fiber a few things need to be considered; it should minimize signal loss as well as maintain the spectral characteristics of the light transporting from the ruby to the spectrometer. To meet these requirements we need to look at the attenuation, numerical aperture, core diameter, wavelength range, dispersion as well as make sure it is compatible with our system.

In order to reduce the intensity and spectral content loss of the fluorescent light coming from the ruby we need a fiber with low attenuation. Generally, single-mode fibers are a better option for low attenuation compared to a multimode fiber. This is due to the way a single-mode fiber propagates light. Single-mode fibers only allow one mode of light to travel through the fiber core which reduces scattering and modal dispersion. This allows for single mode fibers to transmit signals over longer distances with minimal signal loss. In multimode fibers the fiber core is larger and allows multiple modes to propagate within it, which can cause modal dispersion and signal degradation over a shorter distance.

The Numerical Aperture (NA) of the fiber determines its capacity to collect light and at which angle it collects light. For our system we want a higher numerical aperture to ensure the light is fully captured and that it maintains its characteristics. Generally a single-mode fiber has a lower numerical aperture compared to a multimode fiber. Due to the single-mode fiber having a smaller NA it is a more focused and narrower acceptance angle for the light which causes for a limited range of angle allowing more efficient and higher spatial resolution. Whereas Multimode fibers often have a higher numerical aperture. This allows them to accept the light from a higher range of angles which is beneficial for short-distances. The numerical aperture can vary within our project.

In various applications surrounding spectroscopy a smaller core diameter is usually preferred as it collects light better and provides a higher spatial resolution. The smaller core diameter allows the fiber to transmit one mode of light minimizing modal dispersion and allowing a long travel distance with a low attenuation. The larger core diameter promotes multimode light propagation, which can ultimately cause modal dispersion over shorter distances. When looking at the various core diameters of fibers, single-mode fibers are considerably smaller than multimode fibers. Typically single-mode fibers range from a core diameter of 8-10 micrometers whereas multimode fibers typically range from 50 to 63 micrometers.

The last two conditions to keep in mind are the wavelength range and the compatibility to our system. When looking through various optical fibers we need to ensure that the fiber can transmit light in the 300 nanometer to 800 nanometer wavelengths range. It will also have to be implemented into our system, therefore it will need to be flexible and be able to be mounted on either side of the fiber.

Within spectrometer applications generally a single-mode fiber is preferred as it allows for less modal dispersion, and has a lower attenuation. Although we are only transmitting light along a short distance we want as little signal loss as possible to ensure that we are collecting all the different fluorescent excitations from the ruby.

3.2.2.10 Slit

Once the excitation source has interacted with the ruby and fluorescence excitation occurs, it will travel through the fiber and the light exits through a narrow vertical slit. The width of the slit is an important factor when designing the resolution of the REID. A larger width means more optical power which can reduce the amount of time required to obtain an accurate reading. However, the smaller the slit, the wider the resolvable bandwidth of the absorption spectrum. When selecting the width size there are sizes ranging from anywhere between 5 micrometers to 800 micrometers. In order to calculate the width desired for the REID this equation was used.

$$t = 1.9\sqrt{d} * \lambda$$

This equation represents the distance between the slit to the image, λ represents the maximum transmittance wavelength. This means we need a slit width around XX. For the REID we decided to choose a slit size of XX. Due to the slit width not being a big factor within our application we can adjust the width for any reason.

3.2.2.11 Grating

There are two dispersion optics that are often considered for the analysis of a fluorescent spectrum, a diffraction grating or a prism. To determine the type of dispersion element to use we mainly need to look at the desired resolution of at least 5 nanometers. Prisms can be hard to buy commercially for small projects as prisms are made custom to fit the various factors for its desired application, because of this prisms are more expensive and harder to obtain. Due to these constraints the REID will utilize a diffraction grating.

Diffraction gratings are optical devices that enable the separation and analysis of light into its constituent wavelengths. Diffraction gratings allow scientists to study unique spectral fingers of various objects ranging from many different distances. In this section, we will investigate the inner workings of diffraction gratings, the role they play in spectrometers, the two main types of gratings, the calculation of groove spacing, and the key concepts of order of diffraction and incidence angle.

How Diffraction Gratings Work

Diffraction gratings work on the principles of wave interference. When a light source hits a diffraction grating it interacts with the parallel lines or grooves that are closely spaced. This interaction causes the light to be dispersed into its individual component wavelengths forming a spectral pattern. This occurs due to the superposition of the light waves that pass through the gratings.

Each line in the diffraction grating acts as a separate source of secondary waves. Diffraction orders are created by the constructive and destructive interference between the light waves and the secondary waves. The central order, m=0, relates to the undeviated direct beam of light. Higher orders, m = <1, then are formed on each side of the undeviated beam; these represent diffractive light from various angles and correspond to different wavelengths.

Use of Diffraction Gratings in Spectrometers

For a spectrometer the diffraction grating is one of the most important components. The main role for the diffraction grating is to disperse light according to its wavelength. This allows the user to measure and analyze the intensity of each wavelength separately. In a standard spectrometer light is collimated from a source and directed into a diffraction grating. The grating then disperses the light at different wavelengths, and focuses into a detector that is positioned at a specific angle from the grating in order to collect the diffracted light. The angle of the grating and the detector is important as the change in the angle can vary the different wavelengths that are collected. We need to ensure that we are focusing the light to ensure the detector collects all various wavelengths. By doing this it will provide valuable information about the ruby being tested.

Two Different Types of Diffraction Gratings

There are two primary types of diffraction gratings: ruled gratings and holographic gratings. Each has their own benefits and applications, which will be discussed as follows.

A ruled grating is produced by physically engraving closely spaced grooves onto the surface of a substrate, typically using a diamond-tipped tool. Ruled gratings are known for their durability and can be customized with specific groove densities for specific applications. They are commonly used in spectrometers that require high-resolution and accuracy.

Holographic gratings are created through a more intricate process. A holographic interference pattern is exposed onto a photoresist-coated substrate, and after development, this pattern becomes the grating. Holographic gratings offer several advantages, including excellent optical quality, low stray light, and the ability to produce gratings optimized for a wide range of wavelengths. These gratings are often preferred for spectrometers that cover a broad spectral range.

Calculating Groove Spacing

Groove spacing, also known to be line density, is a key specification for a diffraction grating. This will determine the dispersion and the range of wavelengths of light that will be separated by the grating. The formula to calculate line density (d) is given as:

$$d = \frac{\lambda}{m^{*}sin(\theta)}$$

Where λ is the wavelength of light, m is the diffraction order and θ is the angle of diffraction. For REID the

Diffraction Angle and Blazed Angle

The diffraction angle (θ) is the angle at which the diffracted light hits the detector. The diffraction angle is essential to determine the spatial separation of the different spectral components. The diffraction angle is a function of both the wavelength (λ) and the groove spacing (d), as described in the groove spacing calculation.

The blazed angle (θ_B) is the angle the grating is oriented to achieve the highest efficiency at any specific wavelength, known as the blaze wavelength (λ_b). When designing a spectrometer, it is important to keep the blaze angle in mind. Blazed diffraction gratings eliminate all of the diffraction orders except one that includes the zeroth order if it is not selected, this is to optimize the grating efficiency, which can be found by quotient of the diffracted power and the incident power of the light. Due to the fact that gratings are not lossless tools, a high grating efficiency is needed so the system can achieve a maximum signal throughput. The blaze angle is calculated by the following equation:

$$\theta_B = sin^{-1}(\frac{m\lambda_B}{2d})$$

The blazed angle is essential for maximizing the efficiency of the grating at the desired wavelength and ensuring that the desired order of diffraction is enhanced. Where m is the diffraction order, λ_B is the blaze wavelength and d is the groove spacing.

The grating should be blazed at the angle of maximum efficiency for a ruby. To find this, use Equation XXX with the parameters $m = 1$ and $\lambda = 694$ nanometers. Since d is typically a standardized number, this can be varied with those known quantities to produce a blaze angle that matches the m and λ values.

In conclusion, diffraction gratings are vital tools that enable the separation and analysis of light by its constituent wavelengths, making them indispensable in spectrometers. Ruled and holographic gratings are the two primary categories, each offering specific advantages. Parameters such as groove spacing, diffraction angle, and blazed angle are critical for designing and using spectrometers effectively. These versatile optical components empower scientists and researchers to unravel the secrets of the universe, one spectral line at a time.

3.2.3 Electrical Components

3.2.3.1 Sensor System

The sensor is arguably the most important part of a spectrometer, without it all the rest of the set up would be useless. When researching what type of detector to use we were trying to utilize the detectors that are easily compatible with familiar software programs and its ability to obtain a good resolution for the incident beam of light ranging from 600 nanometers to 700 nanometers waveband.

Raspberry Pi 4 Emission Acquisition Sub-System

The reader will note that there are multiple ways to acquire the type of spectral emissions we are interested in for this project. Among these, microcontrollers and single-board computers (SBCs) are both essential components in the world of spectral analysis, embedded systems and the internet of things (IoT). They both play significant roles in various applications, but they differ in terms of their capabilities, use cases, and design. A microcontroller is a compact integrated circuit designed for specific tasks, typically within embedded systems. Key characteristics of microcontrollers include: Low power consumption; Specialized for dedicated tasks; Limited computational power and memory; Often used for real-time applications; Typically include input/output pins for interfacing with the external world; Minimal operating system or no operating system. Some popular microcontroller families include: Arduino (ATmega series); Raspberry Pi Pico (RP2040); STM32 (ARM Cortex-M series); PIC (PIC16, PIC18, PIC32).

SBCs possess the following characteristics: More processing power and memory than microcontrollers; Typically run a full operating system (Linux, Windows); Suitable for general-purpose computing; Provide various connectivity options (USB, Ethernet, Wi-Fi); Used for both prototyping and production. Applications for SBCs range from Education and prototyping (learning to program, experimenting with hardware) to Media centers and entertainment (e.g., Raspberry Pi running Kodi) and IoT gateways (handling data aggregation and communication) all the way to Industrial applications (data acquisition, control systems). Some popular SBCs include: Raspberry Pi (various models); BeagleBone; Odroid (various models); Intel NUC (Next Unit of Computing); NVIDIA Jetson series.

While both types of platforms are quite similar in what they can accomplish, there are distinct differences. Microcontrollers are designed for low-power, specific tasks with limited computational power and memory. In contrast, SBCs offer significantly more processing power and memory, making them suitable for a wide range of applications. Microcontrollers often run minimal or no operating system, while SBCs run full-fledged operating systems like Linux. This difference allows SBCs to handle multitasking and diverse software. SBCs typically come with various connectivity options, including USB, Ethernet, and Wi-Fi, making them versatile for different applications. Microcontrollers often require additional components to achieve similar connectivity. Microcontrollers are generally more cost-effective and are preferred for low-budget projects, while SBCs tend to be more expensive due to their enhanced capabilities. Microcontrollers are best suited for dedicated, real-time, and power-efficient tasks, while SBCs excel in applications that require general-purpose computing, multitasking, and connectivity.

The reader may recall that Spectroscopy operates on the fundamental principle that different materials absorb, emit, or scatter light in distinct ways. By examining the resulting spectral patterns, scientists can deduce valuable information about the substances under investigation. Spectroscopy is also a non-destructive technique, making it suitable for a wide range of applications. In our setup, our useful information is generated starting with emissions from the ruby. Ultimately, the emissions are read through the spectrometer which in turn starts the characterization process. In conjunction with the spectrometer we have devised a sub-system. This subsystem involves the use of the Raspberry Pi single-board computer (SBC). Our reasoning behind using this particular SBC is based on multiple factors including power consumption, useful utilities, cost, adaptability, among other things. Our sub-system components include the following: Raspberry Pi 4, Pi camera, diffraction grating spectroscope, CCTV lens, green LED, and white LED. This sub-system can be seen as a system for "emission data acquisition."

The Raspberry Pi is a series of small, affordable, single-board computers designed for educational and hobbyist purposes. Developed by the Raspberry Pi Foundation, these credit-card-sized computers offer significant computing power in a compact form factor. They are equipped with various hardware interfaces, including USB, HDMI, GPIO pins, and Wi-Fi, making them highly versatile.

Raspberry Pi computers run on the Raspbian operating system, a Linux-based distribution optimized for the Pi's hardware. These devices are known for their ease of use, low power consumption, and extensive community support. Raspberry Pi has gained popularity as a platform for numerous applications, including robotics, home automation, and, increasingly, scientific experimentation.

To be clear there are different models of Raspberry Pi available:

- Raspberry Pi 1 Model A and Model B:

    - These were the first Raspberry Pi models, with limited processing power and memory.
- Raspberry Pi 2 Model B:
    - An improvement over the first generation, offering better performance and more memory.
- Raspberry Pi 3 Model B:
    - Quad-core processor and integrated Wi-Fi and Bluetooth, the Raspberry Pi 3 was a significant upgrade.
- Raspberry Pi 4 Model B:
    - Quad-core ARM Cortex-A72 CPU and support for up to 8GB of RAM. It offers USB 3.0 ports and dual HDMI outputs.
- Raspberry Pi Zero and Zero W:
    - Compact and affordable models designed for embedded and IoT projects.

The model of interest in our case is the Raspberry Pi 4 Model B. With each model there is hardware that must be used. This of course may change according to the model. In our case for spectroscopy, these are the basic requirements:

- Raspberry Pi: (this is the actual SBC mentioned above)
- MicroSD Card: A microSD card (16GB or larger) is used to store the Raspberry Pi's operating system and your spectroscopy software.
- Power Supply:
- Display and Input: You can use a monitor with HDMI input for displaying the Raspberry Pi's desktop environment. Additionally, you'll need a USB keyboard and mouse for interaction.
- Internet Connection: For software installation and updates, it's advisable to connect your Raspberry Pi to the internet. You can use an Ethernet cable or Wi-Fi, depending on your model.
- Spectroscope Kit: The key components of a spectroscope include a diffraction grating, a slit, and a sensor (e.g., a camera).
- Additional Peripherals: You might require other peripherals such as breadboards, sensors, and LED lights, depending on your project's complexity.

It might not yet be apparent to the reader why our selection of this Raspberry Pi model is appropriate for this project. By way of comparison, we can make the following observation with various microcontroller type platforms. One of the key advantages of Raspberry Pi is its ability to run a full-fledged operating system (OS) like Raspberry Pi OS, based on Linux. This enables it to perform a wide range of tasks, from serving as a basic desktop computer to running web servers and media centers. Raspberry Pi also features built-in support for wireless connectivity via Wi-Fi and Bluetooth. Arduino, on the other hand, is a brand of microcontrollers rather than single-board computers. Arduino boards are equipped with microcontrollers from the Atmel/Microchip family, such as the ATmega series, which are known for their low power consumption and simplicity. These boards consist of digital and analog input/output pins that can be easily programmed to interact with various electronic components. Arduino boards are designed to be embedded into specific projects and are not intended to run full operating systems. They rely on a sketch-based programming environment that simplifies the process of writing code to control attached hardware. Arduino boards usually lack features like HDMI output, Ethernet, or native Wi-Fi/Bluetooth support, which are common in Raspberry Pi boards.

Raspberry Pi runs a full-fledged operating system, typically a variant of the Linux kernel. This allows it to support a wide range of programming languages and software development tools. Python, in particular, is the de facto programming language for Raspberry Pi, making it an excellent choice for both beginners and experienced developers. It can run web servers, databases, and other software applications. The ability to run a full operating system also enables multitasking and the use of graphical user interfaces, making Raspberry Pi suitable for projects that require user interaction. Additionally, you can install various Linux-based software packages, which opens up opportunities for diverse applications.

Arduino's software environment is more specialized. It uses a simplified version of C/C++ for programming, making it accessible to beginners. The Arduino Integrated Development Environment (IDE) is user-friendly, with a straightforward code editor and a library of pre-written code snippets. However, Arduino lacks the capability to run a full operating system, limiting it to a single, dedicated program. This simplicity is advantageous in terms of low latency and real-time control, making Arduino suitable for projects that require precise timing and responsiveness, such as robotics, automation, and sensor data acquisition.

Both Raspberry Pi and Arduino serve as powerful tools in the world of electronics and DIY projects, but they cater to different needs and preferences. Raspberry Pi, with its full operating system and robust software support, is suitable for a broad range of projects, including those that require web connectivity and user interfaces. Arduino, with its real-time control capabilities and extensive hardware compatibility, is ideal for embedded systems and applications that require precise timing and interaction with sensors.

Another comparison can be made with NanoPi, which is another type of SBC. NanoPi is a series of SBCs developed by FriendlyELEC. These SBCs are designed to cater to the growing demand for small, cost-effective computing solutions for various applications. The NanoPi series has been competing with Raspberry Pi, offering alternative choices for SBC users. NanoPi SBCs typically offer 1GB to 4GB of RAM. The exact RAM size may differ between different NanoPi models. In addition, NanoPi boards usually use microSD cards for storage, similar to Raspberry Pi. Some NanoPi models include eMMC storage options for faster and more reliable storage. Similar to Raspberry Pi, NanoPi boards feature USB ports, Ethernet, and some models include Wi-Fi and Bluetooth capabilities.

In terms of graphics, NanoPi SBCs use Mali GPUs, typically Mali-450 or Mali-400. The GPU performance may differ depending on the specific NanoPi model. Also similar to Raspberry Pi, NanoPi supports popular Linux distributions such as Armbian, Ubuntu, and FriendlyCore. A distinction can be made between the two platforms in this regard. Whereas, Raspberry Pi benefits from its wide user base, making it compatible with a broad range of applications and software and many software packages are optimized for Raspberry Pi, NanoPi may require more effort to find compatible software for specific models due to its smaller user base.

In terms of performance, NanoPi models vary in CPU performance, but most quad-core options offer reasonable performance for a wide range of tasks. NanoPi models with Mali GPUs offer good graphics performance, making them suitable for multimedia applications. NanoPi models typically have 1GB to 4GB of RAM, making them suitable for lighter tasks and embedded systems. Some NanoPi models feature eMMC storage options, offering faster and more reliable storage performance.

Of particular interest in the emission acquisition is the use of a camera in the Raspberry Pi 4 sub-system. The Raspberry Pi Camera is a compact and lightweight camera accessory specifically designed for Raspberry Pi boards. It connects to the Raspberry Pi's dedicated CSI (Camera Serial Interface) connector, making it easy to integrate with the board. The camera module is typically a small, rectangular device that can be mounted on the Raspberry Pi.

3.3 Strategic Components and Part Selections

3.3.1 Optical Components

LEDs

The green and white LEDs for this project will need to be of a high intensity to ensure the ruby is properly illuminated in the system. The green LED will need to have an emission wavelength of 550 nm in order to properly fluoresce the ruby. The white LED can be incoherent as it is a simple illumination source.

Green LED

Specification			
Manufacturer	Lumileds	Wurth Elektronik	Lumex
Model	L128-PCG20L3500000	156125M173000	SML-LX1206UWW-TR
Power Rating	726 mW	78 mW	70 mW
Luminous Flux/Intensity	145 lm	28 mcd to 280 mcd	90 mcd
Forward Voltage	36.7 V	2 V, 3.3 V	3.5 V
Price (1)	$0.41	$1.25	$1.23

With the given specifications above, the Lumileds LED at 550 nm was decided to be the best option for REID.

White LED

Specification			
Manufacturer	Cree LED	Lumileds	Cree LED
Model	XPGEWT-01-0000-000 000RE2	L2C5-40901208H15 00	XHP50D-H0-0000-0D0ZF440G
Forward Current	700 mA	900 mA	6 A
Luminous Flux/Intensity	382 lm	4894 lm	808 lm
Forward Voltage	2.8 V	34.2 V	11.2 V
Price (1)	$1.62	$11.80	$6.72

From the given specifications, it has been determined that the first Cree LED option will be the best component for the project.

Beamsplitter

When considering what type of beam splitter to integrate into our system, various specifications need to be considered. The size of the component must not be too large as to add unnecessary expense to the project as well as not too small where not enough input light will be transmitted or reflected. In addition, whether to use a plate or cube beamsplitter will also need to be considered. The wavelength range this project will operate in will be entirely visible, so beamsplitters within 400-700 nm will be the sole consideration. This component will need to have an equal reflection to transmission ratio to optimize the output of both optical systems and ensure no unnecessary losses occur.

Specification				
Manufacturer	Edmund Optics	Edmund Optics	Thorlabs	Thorlabs
Construction	Plate	Cube	Plate	Cube
Model	#45-313	#32-600	BSW04	BS007
Diameter (mm)	12.50	5.00±0.10	12.70	5.00
Thickness (mm)	1.00	5.00±0.10	3.00	5.00
Substrate	Float Glass	N-BK7	Fused Silica	N-BK7

Reflection/Transmission Ratio	50/50	50/50	50/50	50/50
Wavelength Range (nm)	400-700	400-700	400-700	400-700
Price	$46.00	$177.00	$104.81	$174.70

From this table, we can conclude that the Edmund Optics plate beamsplitter will achieve what this project needs for the cheapest price.

Lenses
Lens design is underway, as Zemax licensing needs to be acquired and parts will be chosen once that development has finished.

Prisms
The right angle glass prisms in this application will need to match the size of the calcite rhombus, have no coatings, and be of a price within a college student's budget. There will need to be two of them, but they will be identical as they serve the same purpose of guiding the light in and out of the calcite block.

Specification			
Manufacturer	Labnique	StayMax	NYJLGD
Model	MT-RAP-25	SMax-00015	ZJGJ-30
Substrate	K9 Optical Glass	N-BK7	K9 Optical Glass
Dimensions	25 mm x 25 mm x 25 mm	30 mm x 30 mm x 30 mm	30 mm x 30 mm x 30 mm
Price (1)	$16.95	$18.99	$9.99

While the third option seems very cheap for a similar product to the first option, Labnique has a more reputable consumer base. While a cheaper price would be nice, the Labnique prism would be the best choice.

Mirrors
The mirrors to be considered would need to have a coating that reflects the wavelength range that REID will operate in with high reflectivity. They will need to be cost-efficient and easily mounted within the system. There will need to be two of them for adjustment of the optical axis.

Specifications			

Manufacturer	Edmund Optics	Thorlabs	Edmund Optics
Model	#32-940	PF05-03-G01	#43-866
Reflectivity	$R_{avg} \geq 95\%$	$R_{avg} > 90\%$	$R_{avg} \geq 95\%$
Wavelength	450 - 650 nm	450 nm - 2 µm	450 - 650 nm
Diameter	5.00 ± 0.25 mm	0.5 in	6 x 6 mm
Price (1)	$23.00	$39.03	$23.00

For REID, a square mirror would be more easily mountable into a 3D printed system. Because the two mirrors are the same price, the optimal option would be the second Edmund Optics mirror.

Calcite

For the REID the calcite will need to be as clear as possible while remaining within budget constraints. There are treated calcite specimens where they're made to be more clear, however this can drive up the price of them fairly quickly. In addition, many samples are charged per gram in addition to the clarity, so size will be considered. Smaller samples may be better for maintaining the desired portability of the system but may not be optimal for maximum light collection.

Specification			
Brand	3B Scientific	Earth Gems	jjlminerals
Size	22 mm x 16 mm x 12 mm	70 mm x 50 mm x 23 mm	3.5 cm x 3.5 cm x 2.5 cm
Clarity (by personal judgment)	Good	Good	Excellent
Weight	0.03 lb	226 g	77 g
Price	$38.00	$27.93	$60.00

From the above table, we can concur that the Earth Gems calcite will be the most cost effective option. While splurging on the highest quality calcite would be nice, it would not be within our budget constraints.

Electrical Supply/Components

The electrical set up and power requirements of this project is as follows. For each component in our set up there does not appear to be many variations in terms of the type of power needed for the devices. The main components that will be of interest are the spectrometer, photodetector, rotating stage, dichroscope, the display, and lamp source.

Note that the spectrometer is available as one unit in which case the power supply is the standard 120 VAC. If we decide on using each of these as a separate unit, their respective power sources may differ. For example, a handheld model for the spectrometer will come with a 120 VAC adapter. As a variation, the spectrometer can also be powered through USB by using either the Arduino or the Raspberry Pi architectures. In these cases, the power supply can be as low as 9 VDC.

Assuming that the photodetector (photodiode) will be a separate unit, the photodiode uses the photovoltaic effect. This uses the creation of a voltage across a p-n junction of a semiconductor when the junction is exposed to light. The simplest form of the photodetectors is a p-n junction device operated under reverse bias condition. Thus, the requirement of a power supply source is essential for the operation of photodetectors. Typically, the photodetector would be used with a battery.

An alternative to the battery operated photodetector is the self-powered photodetectors. These are a class of devices which requires no external power supply for their operation. The working of self-powered photodetectors is closely related to that of the photovoltaic devices operated under short-circuited mode or open-circuited mode. The self-powered photodetectors can be classified into two types. The first type of self-powered photodetectors independently generates sufficient power on their own and they do not require any external power supply or a separate energy harvesting unit for their operation. The second type of self-powered photodetectors is the integration of the conventional photodetectors with a separate energy harvesting unit which supplies energy required for the operation of the photodetectors connected to it.

The rotating stage is powered by standard 120 VAC. The dichroscope has no external power source. The display will be on a computer screen or a monitor through USB or HDMI compatibility. The laptop will require a power supply of either 12 VDC battery or 120 VAC. The monitor will require 120 VAC.

3.3.2 Electrical Components

There are several types of versions of cameras. The original Raspberry Pi Camera Module features a 5-megapixel sensor and is capable of capturing 1080p video at 30 frames per second. It's a cost-effective option for basic photography and video projects. Next, an improved version, Raspberry Pi Camera Module (v2.1), comes with an 8-megapixel sensor and better image quality. It supports 1080p video at 30fps and 720p video at 60fps. Then there is the Raspberry Pi NoIR Camera Module (v2.1) (No Infrared) version is identical to the regular v2.1 camera but lacks the IR filter, making it suitable for low-light and night-vision applications when used with IR lighting. Finally, Raspberry Pi High-Quality Camera features a 12.3-megapixel Sony IMX477 sensor and interchangeable lenses. This one offers exceptional image quality and is ideal for professional photography and video projects.

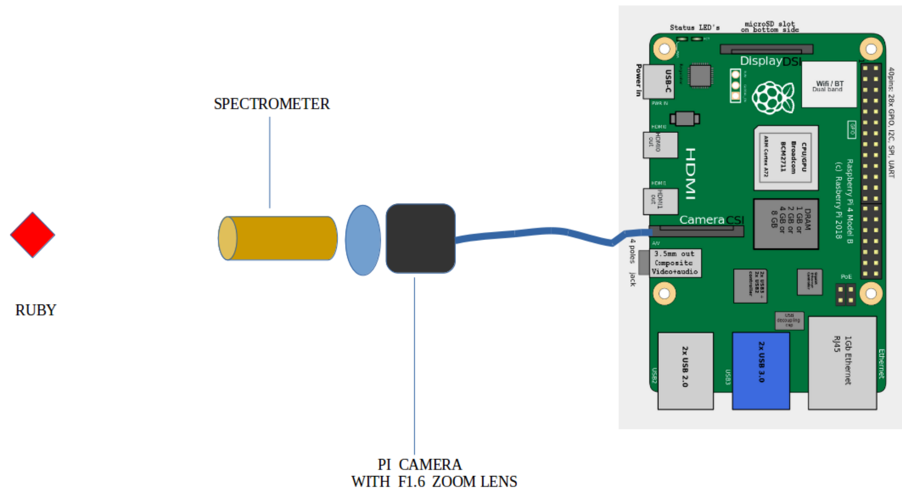


Figure 4: Emission Data Acquisition Subsystem Including Raspberry Pi 4B (cf. Appendix A)

3.3.2.1 Raspberry Pi 4 B, Basic Features / Accessories

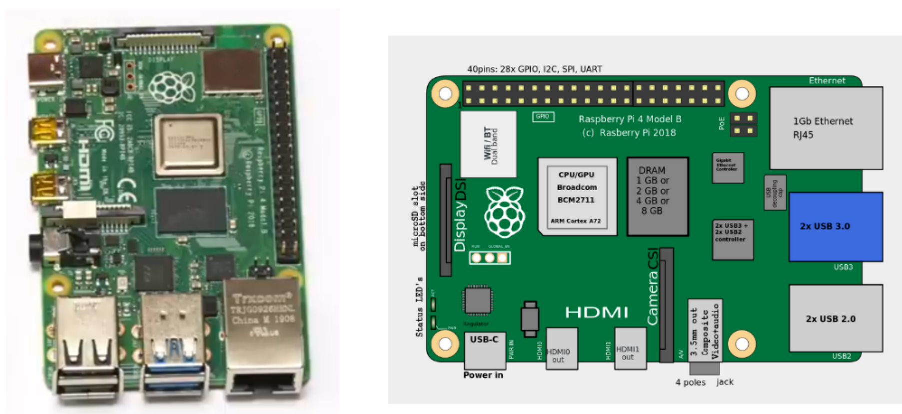


Figure 5: Raspberry Pi 4B (cf. Appendix A)

This version of the Raspberry Pi SBC follows the IEEE 802.11b/g/n/ac wireless protocol and Bluetooth 5.0. As the reader will note in the images above, there is a USB 2.0 connector (two ports), a USB 3.0 connector (two ports), and a gigabit ethernet connector. We may also note the USB-C port for the power supply (5 V, ~ 3 A), two 4K (resolution) micro HDMI ports, one 3.5mm stereo audio and composite video connector. There is also the 40-pin GPIO and below it is the 4-pin power-over-ethernet (PoE) connector. This version uses Broadcom BCM2711 system-on-chip (SoC) with 64-bit, quad core ARM Cortex-A72 CPU at 1.5GHz.

In the image below, we can see on the right side the slot where the micro-SD card may be inserted after the appropriate software has been imaged on it.

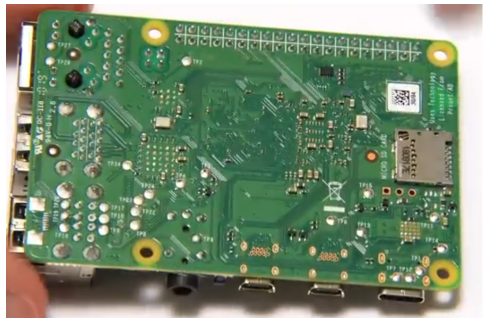
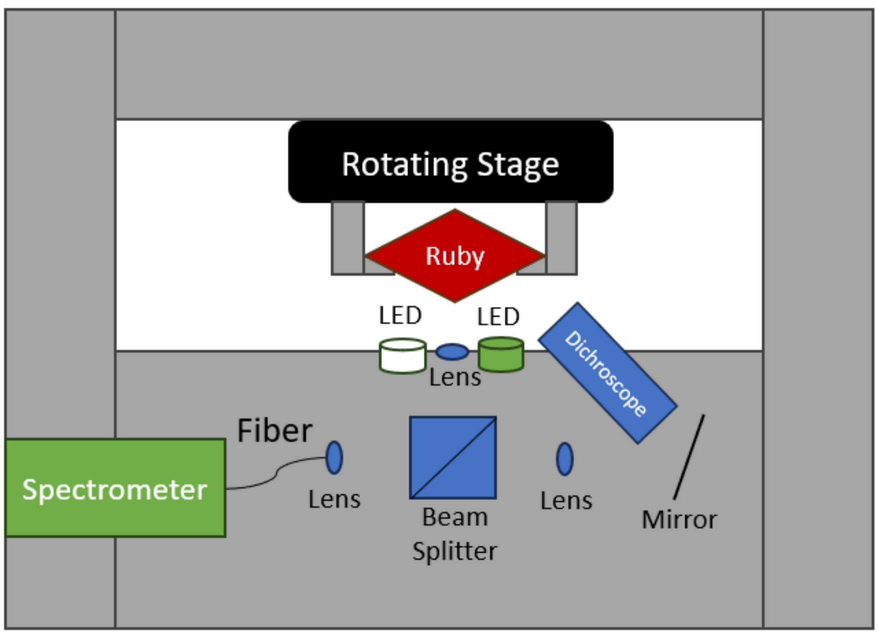


Figure 6: Raspberry Pi 4B (cf. Appendix A)

Typical accessories that come with this SBC include the following: USB-C power supply (5V, 3A), 2 HDMI to micro-HDMI cables, case, mouse, keyboard (with 3 internal USB ports). Not included are the following: micro-SD card, SD card reader, USB-C to micro-SD card adapter, camera.These last three are critical in order to setup the software appropriately.

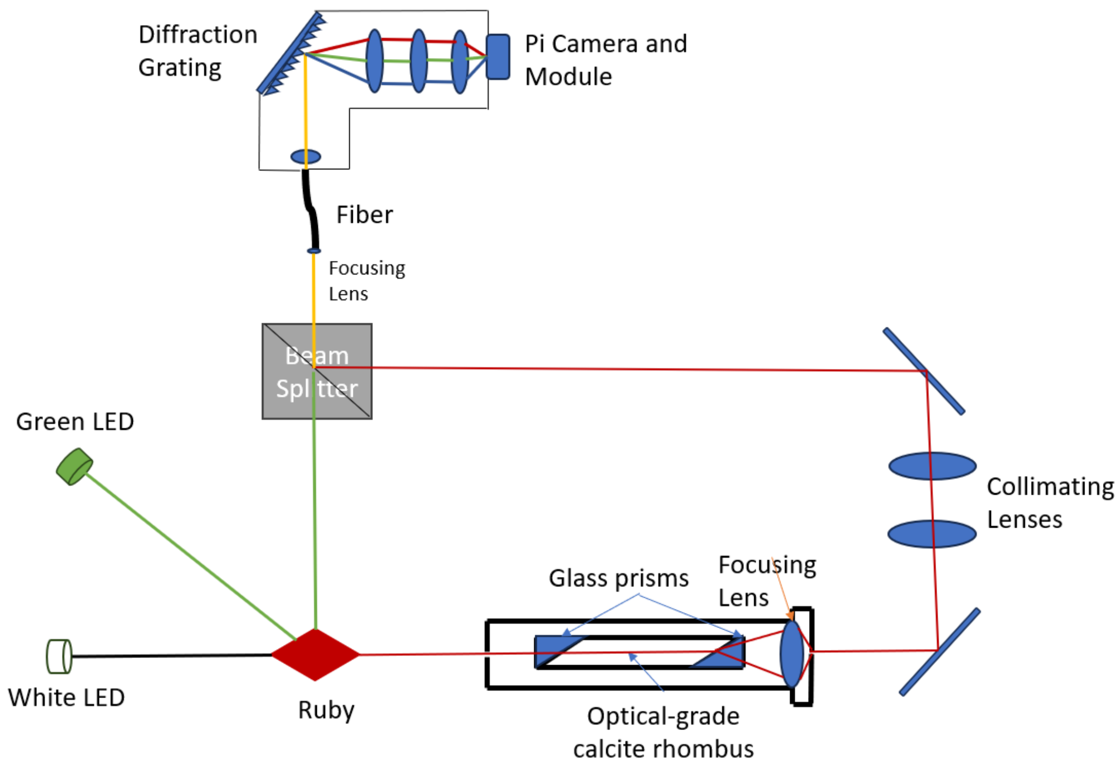
3.4 Possible Architectures and Related Diagrams

3.4.1 Overall System



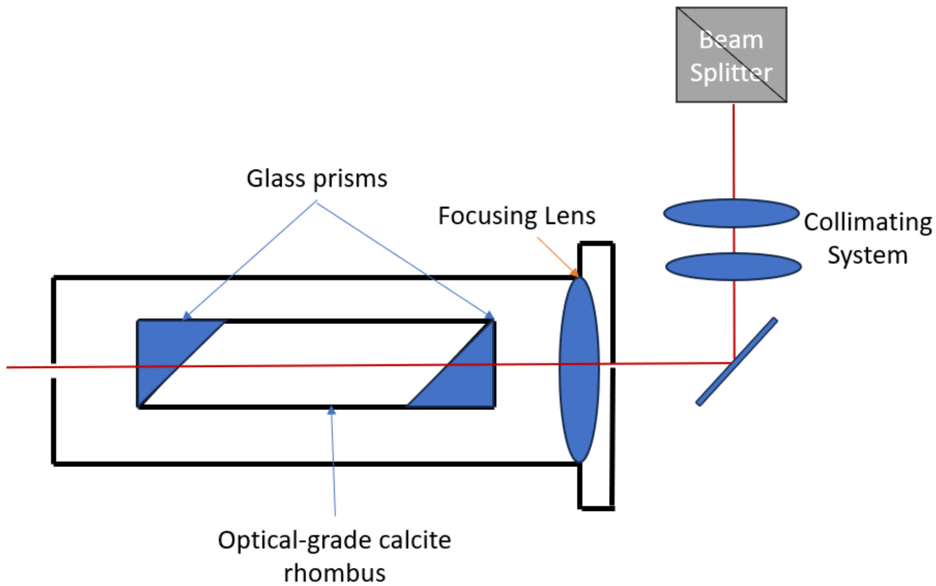
The overall system will be a top-down design. The top of the box will open to reveal an adjustable receptacle that will hold the ruby in place. This is to account for jewelry but it will be up to the user to properly place the sample into the chamber. The receptacle is attached to the rotating stage so that the ruby can be properly rotated without impacting the optical components. The LEDs will be placed at an off-angle with respect to the ruby to minimize surface reflections that will directly enter the lens. The lenses are simplifications of focusing/collimating systems that will be designed to minimize the beam size for optimal fiber alignment. The dichroscope is also placed at an angle that will have minimal interference from the white LED light and will allow for adequate room for the rotation stage and ruby. A beam splitter will be utilized to simplify the optical system and implement the dichroscope into the spectrometer without jeopardizing the focusing lens that will directly view the ruby. The spectrometer will have an input fiber that will take both the fluorescence and dichroscope light for measurement.

3.4.2 Overall Optical System



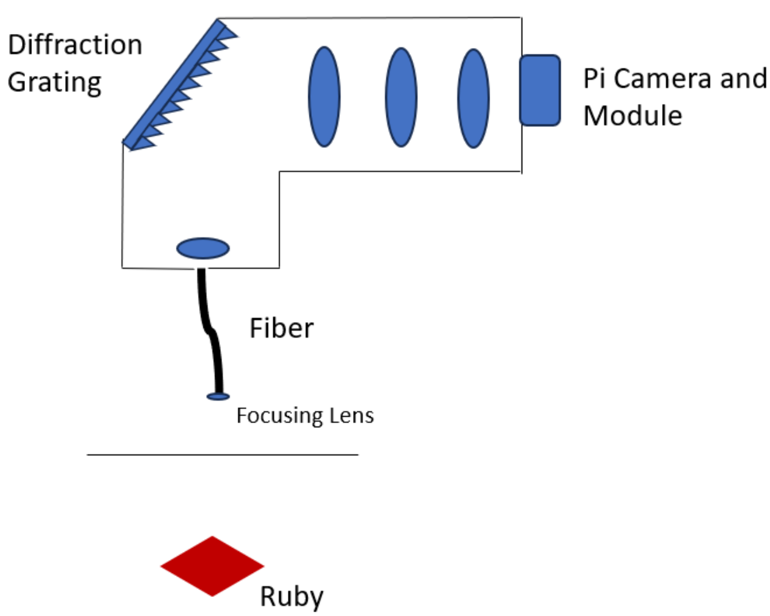
This is a simplified diagram of the ray tracing of the optical setup. The green LED will fluoresce the ruby and the light will directly enter the beam splitter and get focused into the fiber. The dichroscope is pictured in the lower right. The emitted light from the ruby will enter the calcite and be split into its separately polarized rays. These beams will be focused and redirected via mirrors onto the beam splitter and into the fiber. Any light entering the fiber will enter the spectrometer for analysis.

3.4.3 Dichroscope



The dichroscope features an initial aperture that will block out ambient white light from the LED. It has two glass prisms on either side of an optical-grade calcite rhombus that will help guide the light more efficiently through the birefringent material. From there, the diverging rays will be focused via a lens onto a mirror that will redirect the light through a collimating system. Finally, the light will travel through the beam splitter into the fiber.

3.4.4 Spectrometer



For the spectrometer four lenses are utilized, along with a diffraction grating and a PI camera accompanied with a module. The first lens will be used to collimate the light from the fiber, and it will be separated into its constituent wavelengths via a diffraction grating. The beam will then be focused and separate the different wavelengths that will then be read by the detector.

3.5 Parts Selection Summary

System	**Part**	**Acquisition**	**Cost Per Unit**
Housing	Rotating Stage	Purchase	$17.99
Housing	Shield	3D Printing	$0.00
Testing	Synthetic Ruby	Purchase	$20.00
Spectrometer	Lenses	Purchase	–
Spectrometer	Fiber	Purchase	–
Spectrometer	Diffraction Grating	Purchase	–
Spectrometer	Pi Camera	Purchase	$50.00
Spectrometer	Pi Module	Purchase	$19.99
Spectrometer	550 nm LED	Purchase	$2.04
Dichroscope	Mirrors	Purchase	$23.00
Dichroscope	Beamsplitter	Purchase	$46.00
Dichroscope	Calcite	Purchase	$38.00
Dichroscope	Apertures	3D Printing	$0.00
Dichroscope	Prisms	Purchase	$57.00
Dichroscope	Lenses	Purchase	–
Dichroscope	White LED	Purchase	$1.56

4 Related Standards & Real World Design Constraints

4.1 Related Standards

ANSI Z535: This is a series of standards that is primarily focused on safety signs, labels, and symbols. It defines the specific colors and designs used for signs and labels and provides guidelines for choosing them in order to convey the desired safety message. As the REID has electrical components that when mistreated could result in an accident, these standards will need to be considered and the appropriate signs made.

ANSI Z10: This set of standards outlines manufacturing workplace guidelines, including safety objectives and targets, leadership and employee commitment, audits, documentation and record keeping, and legal workplace safety requirements that ensure the continuous improvement of safety performance is achieved and implemented within a potentially dangerous workplace. It's applicable to a great range of industries and organizations, and can improve reputation among the workforce for its demonstration of a company's commitment to safety.

ASME Y14: Schematics are a necessary tool for any product design, and this set of standards details exactly how those should be done. There is a wide range of what is defined in this set, which includes but is not limited to: decimal inch drawing sheet size, format, line conventions and lettering, multi and sectional view drawings, dimensioning and tolerancing, screw thread representation, types of engineering drawings and their applications, drawing practices, and digital product definition data (DPD) practices.

ANSI/ESD S20.20: With electronic components comes the need for proper precautions to prevent the discharge of static electricity causing damage to sensitive electronic components and assemblies. These standards detail things such as personnel grounding using wrist straps or other ESP protective equipment, regular compliance verification activities, protective packaging and labeling, protective requirements for workstations, audits and evaluations, and a formal written plan to assist designated ESD control coordinators.

ASTM D4169: As the REID will have optical components with only a certain amount of tolerance, proper packaging will be needed. This standard provides guidelines for the quality of shipping containers as well as procedures on how to test them. These can include shock, compression, drop, incline impact, and loose load tests and are typically done in a lab setting. There is a performance criteria that must be met for each specific packaged product and the environment in which it will be distributed in.

ISO 9001: This is an internationally recognized standard for quality management. It's based on a set of principles that detail customer focus, leadership, engagement, process approach, improvement, decision making based on evidence, and customer satisfaction. These standards implement risk-based thinking, which is identifying risks and opportunities that can impact achievement and quality objectives. Every process must be monitored, measured, and analyzed to ensure products always meet customer requirements. In addition, these processes must always be analyzed for improvement to enhance their performance and effectiveness. To demonstrate compliance with these standards, audits must be conducted by accredited certification people and thus a certification will be obtained.

IEC 60130-10: This standard details the multiple types of connectors that can be used in a very wide range of applications. It describes qualities such as dimensions, mechanical properties, electrical properties, and environmental considerations. Based on these specifications, it details the performance of each of these connectors to ensure compatibility, reliability, and their suitability for the intended applications. It is an older set of standards, and revolves around DC power connectors that operate below 3 MHz. This can be used to connect a power source to a PCB and thus to the rest of the device while ensuring all components receive the right electrical values and don't get burnt, which could pose a hazard to the user and ruin the device as a whole.

Universal Serial Bus (USB): The USB is an industry standard for digital data communications that operate within short distances. It allows data exchange as well as power delivery between numerous amounts of electronics. It's used all over the world and is the main choice when communicating between devices, as it is versatile and excellent at transmitting signals no matter the device type. Due to its wide use, it will be a primary choice for the REID to ensure compatibility across as many devices users may have as possible.

Ruby Standards: Before describing some of the different standards or techniques used in characterization, the reader should note that characterizing rubies is a multifaceted process that involves assessing their physical, chemical, and optical properties, as well as their geographic origin. These properties are crucial for both gemological and mineralogical purposes, including gem identification, valuation, and determining geographic origins. Physical characterization of a ruby can be done in five different ways: crystallography, density, hardness, cleavage and fracture, or refractive index. Each of the properties associated with this type of characterization has its own merit. To provide crystallography data, for example, X-ray diffraction (XRD) is a fundamental technique used to determine the crystallographic structure of rubies. By analyzing the diffraction pattern produced when X-rays interact with the crystal lattice, scientists can precisely determine the unit cell dimensions, symmetry, and orientation of the crystal. Measuring the density of a ruby can provide insights as well into its composition and potential treatments. Density determination involves comparing the gem's weight in air and in a liquid medium of known density, typically using a hydrostatic balance. The density of rubies typically falls within the range of 3.97 to 4.05 g/cm^3. Variations in density can indicate the presence of fillers or synthetic components.

In addition to the previous physical properties, the hardness of a ruby is a key characteristic that contributes to its durability and wear resistance. Rubies are one of the hardest natural gemstones, ranking 9 on the Mohs scale. To assess hardness, gemologists use the Mohs scale and perform scratch tests, comparing the ruby's resistance to scratching with various reference minerals. The extent to which hardness becomes a point of interest for a researcher has an impact in determining a ruby's cleavage and fracture characteristics is important in assessing its durability and value. Rubies often exhibit no cleavage, which means they lack natural planes of weakness where the gem could break. Instead, they typically display a conchoidal fracture, characterized by smoothly curved surfaces when fractured. By contrast, the refractive index (RI) of a ruby, a measure of how much light is bent as it passes through the gem, is essential for evaluating its brilliance and transparency. Gemologists employ refractometers to measure the RI of rubies accurately. The RI for ruby typically ranges from 1.762 to 1.770, with higher values indicating a greater dispersion of light and potential heat treatment.

The chemical properties and associated techniques also provide a unique set of data. The techniques associated with these properties typically include elemental composition, inclusions, spectroscopy, and trace elements. Understanding the elemental composition of a ruby is vital for identifying its authenticity and potential treatments. X-ray fluorescence (XRF) is a common technique used to determine the elemental composition of rubies. By irradiating the gem with X-rays, scientists can measure the characteristic X-ray emissions, which correspond to the elements present. Rubies are primarily composed of aluminum and oxygen, with the red color resulting from trace amounts of chromium. By contrast, inclusions, tiny mineral or fluid-filled cavities within a ruby, can reveal important information about its geological history. Microscopy, particularly high-resolution techniques like scanning electron microscopy (SEM) and transmission electron microscopy (TEM), allows for the examination of inclusions at a microscopic level. These inclusions can help identify the ruby's origin and any heat treatment or filling processes it may have undergone.

The use of the inclusions technique may also involve other techniques such as Spectroscopy. Spectroscopy techniques, including UV-Vis spectroscopy and Raman spectroscopy, play a crucial role in characterizing rubies. UV-Vis spectroscopy measures the absorption and transmission of light in the ultraviolet and visible spectrum, providing information about the ruby's color and potential treatments. Raman spectroscopy, on the other hand, is used to identify the mineral composition and any inclusions within the ruby by analyzing the scattering of light. This technique in turn is related to another called Spectrometry. This latter pertains to investigating the trace elements of a ruby. The presence of trace elements, such as iron and titanium, can influence the color and optical properties of rubies. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), for example, is a powerful technique for detecting and quantifying trace elements. By analyzing the concentrations of these elements, scientists can gain insights into the ruby's geological history and determine its origin.

<u>GIA</u>: The reader may at this point be assessing how exactly one goes about grading or reporting on the authentication of any of the above standards. Currently, there are a list of institutes, both national and international that manage this process. The Gemological Institute of America (GIA) is one of the most renowned gemological institutes globally and has set the benchmark for gemstone authentication. The GIA developed the "Four Cs" system, which assesses gemstones based on carat weight, cut, color, and clarity. This system is widely used for grading diamonds and colored gemstones, including rubies. The Cs are: carat weight, cut, color, clarity. Carat weight is a measure of a gemstone's size. One carat is equivalent to 0.2 grams. The carat weight of a gem is an essential factor in its valuation, but it should be considered in conjunction with other characteristics. The cut of a gemstone refers to its proportions, symmetry, and finish. The quality of the cut can significantly impact a gem's brilliance and overall appearance. For colored gemstones like rubies, color is one of the most critical factors. The GIA grades the color based on hue, tone, and saturation. In the case of rubies, the presence of red with a hint of blue is highly desirable. Clarity refers to the presence of internal and external imperfections or inclusions in the gemstone. The GIA provides clarity grades to assess the extent of these

imperfections. The GIA issues gemological grading reports that detail the Four Cs and other relevant information for individual gemstones. These reports provide essential data for buyers and sellers and are trusted worldwide for gemstone authentication.

IGI: The International Gemological Institute (IGI) is another institute that offers grading and certification services for gemstones. IGI certificates are widely recognized and provide information about the quality and authenticity of gemstones. In addition, the American Gem Society (AGS) is an organization dedicated to consumer protection and ethical business practices in the jewelry industry. AGS has its own grading standards for diamonds and colored gemstones, emphasizing cut quality and providing detailed reports. There are various other international gemological organizations and laboratories who set standards for gemstone authentication. These include the European Gemological Laboratory (EGL), Asian Institute of Gemological Sciences (AIGS), and the Swiss Gemological Institute (SSEF). While standards may vary among these organizations, they all share a commitment to providing reliable gemstone authentication. Obtaining a certification from a reputable gemological laboratory, such as the Gemological Institute of America (GIA) or the International Gemological Institute (IGI), is often the most reliable way to confirm the authenticity of a ruby. These organizations employ advanced equipment and experts to perform comprehensive analyses. The identification of a real ruby involves a combination of visual inspection, laboratory testing, and the use of specialized instruments to assess various physical and optical properties. A trained gemologist or jeweler with access to the appropriate instruments is crucial for accurately determining the authenticity of a ruby.

4.2 Economic Constraints

When developing any product or device for commercial or personal use, the cost of each component and cost of development must be considered. In this portion, as the team members producing this are all unpaid, only the components will be discussed as well as different contributing factors to the device's price point.

The development of the REID will be entirely self-funded by the members of the team. For this reason, each part will be chosen based on getting the maximum quality for a cheaper price. The members of the team are all in college and thus are on a college budget, making it difficult to properly pick parts and ensure maximum quality of the project. Despite this, the REID needs to be a reliable device with parts that will not break down as the device is used. With greater quality comes larger price tags, however this design ensures that each test is able to be fully and accurately accomplished while finding a medium between expensive parts and not jeopardizing quality.

The components of the REID will be purchased singly or in smaller quantities, as opposed to buying them in bulk. This contrasts with the manufacturing process. Components are cheaper per unit when they're bought in bulk rather than on an individual basis, which will add to our design process price tag but will be beneficial for when this product is made on a larger scale. This quality of bulk part buying is also beneficial in the scaling up of this project, as the cost per device will go down and it will be cheaper to produce if we produce more. The overall purchasing price of the REID will need to be adjusted.

In addition to part quality, the size of the system will be designed in accordance with parts rather than the other way around. This is because the system can be 3D-printed for a much cheaper price than purchasing a custom housing. This enables us to have a diverse array of options in terms of part sizes, which is important for any device as prices tend to increase with larger sizes. In addition, keeping things on a smaller scale will encourage less light loss throughout the system so we don't need to buy larger components to have morel ight throughput in the system.

Optical components can be a coin flip on price points in relation to their quality. Larger optics as well as certain components on a smaller scale can be incredibly expensive due to manufacturing complexities. Coatings on the optical apparatus are another factor to be considered, as they would be beneficial in reducing certain optical aberrations or effects that would impede the output quality of the project. To avoid the need for coatings, the REID utilizes only visible wavelengths. This quality was chosen carefully so as to not make the project more expensive and out of scope for our budget.

Overall, the REID is a system that is intended to be a proof-of-concept, thus is minimal in its budget while ensuring its intended goal is accomplished. Now that the world is thankfully out of the COVID-19 pandemic, ordering parts is much easier. Additionally, the widespread use of Amazon or larger shipping companies such as USPS or UPS has made it so shipping prices are not outrageous and are mostly trustworthy at protecting the integrity of parts.

4.3 Time Constraints

Considering that this product is being designed in a two-semester college course, the team is kept on a consistent schedule by personal, group, and academic deadlines. This means that we have our own personal goals of what to achieve in a given day or week, group-enforced objectives that are accomplished at a minimum of a biweekly basis, and the monthly course deadlines.

In the context of the REID, the first four months will be spent understanding the physics behind this project, picking our components based on this knowledge, and purchasing the major components and testing them in order to ensure we can compile the parts in time for next semester. These months will be the timeframe in which our budget and planned amount to spend is finalized, in addition to maintaining a weekly plan to build the system up to our standards. Writing this paper will be done as the group members learn more about the project and what other factors to consider in the making of the device. Schematics will be loosely drawn, as final measurements and dimensions of the project will be finalized upon building the system.

The next five months, including the winter break, will involve ordering all the parts of the system and implementing them into a unified product. This will be where the optical alignment will be done and distances altered in the paper, the electrical components will be acquired, tested, and implemented into the system, and the software will be developed and finalized. The paper will be updated during this time to detail any unforeseen happenstances in the building of the device.

A large factor to be considered is lead times on acquiring parts for the system. Some components can have as large of lead times as six weeks, which is not beneficial for the short time frame of the design of this project. With such long lead times, if there is a delay in the shipping of any important components, such as the PCB or optical parts, then that presents a very large problem for this project. All parts need to be ordered well in advance for testing, setup, and final implementation into the system. Lead times for al components will need to be analyzed and planned for.

The team making this idea a reality is fortunate enough to have several committee members with extensive background and knowledge of the different fields included in the design of the REID. The expertise of these generous experts will help pave the way for the success of this project and potentially save us more time in the development portion. In addition, the past professors who passed their knowledge down onto the team have enabled this project to be a reality. The education garnered from them will make the design of the REID much easier.

The REID will have a shorter time constraint than what's typically seen in industry, as the time frame is less than a year. It will be a collaborative effort, and with enough hard work and knowledge the system will be fully realized within the time constraints given.

4.4 Equipment Constraints

Rubies come in many shapes and forms that will have to be considered within this project. A minimum and maximum ruby size will need to be determined as well as whether the REID will be able to function properly with common jewelry constraints, such as reflection or absorption of different wavelengths within different materials typically used in gem decoration. The dimensional limits of the ruby will need to be calculated and will heavily depend on the dichroscope's capabilities within an optical system. The fluorescence spectra will not depend heavily on the size of the ruby.

Python will be the primary language used in this project. Due to this, the REID will be limited to Python's packages and will have to determine how to integrate them into the different requirements of the system. The package needed for the spectrometer will need to be determined, as well as for the rotating stage. The list of commands each of these components supports will determine what packages will be used in the REID.

REID will not be able to connect to the internet or upload information to a cloud storage. In addition, it will not have bluetooth capabilities. For these reasons, the software and hardware will have to work entirely offline and be stored within a hardware system. Hardware systems are limited by storage and the type of storage system used, this will include options such as a flash drive, hard drive, and solid state drive. Information from the system will have to be transferred to the selected drive via a USB cord due to the lack of wireless capabilities.

3D printers will be used to create the housing for this system. After analyzing the sizes of the 3D printers available, it has been determined that the containment parts of this system will have to be small in scale yet hardy. This will require filament and thorough designing of the optical system as well as electrical component considerations. The housing will need to hold each optical component in place and be heat resistant enough to not melt or be damaged by the LEDs or electrical components. While this may seem like a limitation, the REID is meant to be portable so this will work more to our favor than be a detriment.

Due to the system's requirement for optical alignment, proper equipment that is designed to handle optical components will be necessary. They will need to have a high amount of precision and accuracy in order to ensure proper alignment of the system. While the housing of the system will be custom printed, the tolerance of the slots should be sufficient to properly hold the part and not allow it to wiggle out of place.

The potential for automating the manufacturing of this device and implementing robotics should be reflected on. This would be beneficial to minimize labor costs and ensure more consistency in the output product. The equipment should be energy efficient and meet compliance and safety standards. It will need to be maintained on a regular basis to ensure the longevity of the equipment and lower costs in the long run. Using machines rather than manpower would also benefit the scalability of this product, as it would be less expensive to keep machines running for longer than to have more workers working longer hours.

4.5 Safety Constraints

There are many methods in crystallography that analyze gem qualities, the more precise ones require wavelengths within ranges that are unsafe the the human eye (IR) or have the potential for the user to develop cancer later in life (X-Rays). As this device is meant to be portable and widely available to layman use, it was determined that for the safety of all, visible wavelengths must be used. This enables a much safer user experience as well as more design safety. Safety glasses will not need to be used, much to the benefit of the REID. In addition, high optical powers, such as those utilized by high power lasers, will not need to be used. Finally, no dangerous chemicals will be used in this system so there is no need for containment.

The electrical power requirements of this system will be kept at a minimum to ensure that no parts will be affected by any heat. This has to be considered because the housing of the system will be 3D printed and not made of metal. In addition, at high heats the optical components might be affected. The PCB and wiring within the system will be fully enclosed to ensure that there is no risk of electrocution should someone not know to touch any wiring or sensitive parts within the system. All components will be enclosed to ensure no layman persons will touch any delicate parts.

A concern with 3D printing are volatile emissions that originate from melting down filament. However, with proper planning and a good ethical conscience these emissions for the most part can be avoided. In addition, once recyclable and more advanced filament is developed then it can allow for more sustainable creation of parts as well as safer conditions for printing.

Emergency procedures for this product would most likely come into play should the internal electrical components be exposed or the product is destroyed in such a way that the glass of the optical components is shattered. A safety procedure should either of these events happen will need to be written. This would entail operations such as ensuring the device is unplugged and given time to discharge any remaining voltage, and wearing protective gloves should anything shatter for cleanup.

Due to the inclusion of a rotation stage, noise and vibration constraints will need to be considered. Because the stage is small, there are no major threats to getting something stuck in it other than a few stray hairs or string, and they should be able to be easily cleaned out given the proper tools and procedures. The rotation stage will need to have longevity without the motor getting too noisy, as noise pollution will need to be minimized. If any vibrations occur, it would not be in contact with any operator of the system and thus intense vibrations that could harm the user would not need to be considered.

4.6 Environmental Constraints

Upon first glance, a ruby characterization may not have direct environmental impact (other than manufacturing processes). However, after deep thought into the broader scopes of gemology and its importance, the impact of developing accurate systems to analyze gems becomes apparent.

Consumer awareness when purchasing precious gemstones can help to make more informed and responsible choices. When this long-term effect takes place, then it will force the gemstone industry to incorporate more environmentally friendly and ethical practices into their mining to meet consumer demands. This demand for environmental considerations will force the industry to have more sustainable mining, processing, and transportation methods. These changes will reduce the carbon footprint these practices have as well as diminish the large impacts on local ecosystems, such as deforestation, habitat destruction, and ecosystem disruption. Distinguishing rubies may even prevent unethical mining as a whole. Supporting synthetic rubies, which do not require mining or unethical sourcing practices, can help to prevent the unsustainable mining practices that harm local communities as well as the environment.

Developing this technology will also drive advancements in this type of system that even scientists can use. The need to accurately determine real from fake rubies can lead to even broader applications in scientific research, which can eventually lead to environmental conservation practices and the study of geology that will only benefit sustainability. Once more accurate and non-arguable identification can be achieved, it will reduce mining pressure and thus reduce environmental pressure that is associated with ruby acquisition.

Choosing to 3D print the system has its benefits and negative impacts. On the one hand, it allows for the reduction of waste due to it being an additive process and is energy efficient. In addition, localized production is an amazing benefit to 3D printing parts and parts can be optimized with minimal material usage. However, much of the material used in 3D printing is plastic and thus not sustainable. There is the option of using recycled materials but that comes with its own difficulties. Some 3D printers used in industrial applications have a high energy consumption rate, thus the desire for REID to be as small as possible. Recycling 3D printer materials can be challenging due to the diverse compounds within filament, as well as some of these filaments having the potential for dangerous emissions. As more eco-friendly filaments are developed some of these issues can be mitigated greatly.

4.7 Manufacturability Constraints

The manufacturing of the REID will mostly be inhibited by cost, assembly difficulties, and part availability. Because this product operates in the visible wavelength range, it will make the optical components much easier to acquire and more economically viable. The other components are not specialized or complex, so this enables even more manufacturing availability.

Sourcing the components has multiple factors to consider. Lead times on ordering parts will need to be considered as well as supply chain options and availability. The price of the product could go up or down depending on the current state of available parts, as well as what's available in the workforce.

The optical alignment of the system will be simple once the 3D printed housing is developed and parts can be inserted into slots. The alignment will need to be verified due to anomalies in manufacturing processes, however this should be simple as long as output requirements are specified and able to be tested for. If machines assemble this optical system, then it will remove the potential of smudging the components or otherwise damaging them.

The housing will be 3D printed, however if created on a larger scale a higher quality housing may be used for a more marketable, sleek design. Cushioned slots for the optical components to allow for vibrations or other mechanical stresses would be ideal. In addition, it could allow for more efficient implementation of the electrical components that fit into the housing better and could downsize the product. However, this would require more precise tooling and equipment on the part of the manufacturer. This might not be a problem for companies that specialize in optics, however for companies that specialize in gemology products this could raise an issue. Tolerances for each optical component would need to be considered, as changes in the optical alignment will have an impact on the output of the system.

The software for the REID would have to be developed to be usable across multiple operating systems, such as Linux, Ubuntu, Mac, and Windows. As REID was originally coded using Python, the operating system should be able to be checked and accounted for. This might put more strain on the hardware storage for the system, but installation directions for specific software, say that comes on a USB with the product or available from a commercial website with a verified purchase, would simplify this requirement tremendously.

Manpower in developing any product has to be considered. For the REID, not much physical labor will be required and the majority of testing the device will be testing the optical alignment. However, this would require access to a somewhat skilled workforce. Guidelines on testing will have to be written that is layman friendly so that proper testing can be accomplished without necessitating a whole team of expensive engineers. This will add to the cost of development, but can be downsized should the proper guidelines be put in place.

Transporting this product will need to be considered, as if the product is too large or fragile it will drive up transportation costs. The REID will be done on as small of a scale as possible, with a modular design that can be locked in place. This will ensure stability of the product and lower these costs. Due to the lack of advanced coatings on the optics as well as other design decisions, storing REID will not pose a large issue should the storage be handled properly.

This product, as it is for a specialized audience and not generally for everyone to own one in their home, will not need to have an incredibly large production volume. Should demand rise then the production of REID should be able to be scaled to match what is required, as many of the components aren't specialized.

4.8 Ethical Constraints

In large, the REID is a safe system that should be made with ethical methods. This can include inclusion in the production of the system and ensuring everyone is welcome to use or purchase it. Environmental impact and sustainability has already been discussed, so other portions of ethical considerations will be discussed.

During the manufacturing process of this product, should a company be started around it, fair labor practices as well as inclusivity and accessibility will need to be given priority to the work force operating in the process. Fair wages, safe working conditions, and rights for workers will all need to be considered to ensure a healthy workplace environment. The price of the REID will need to be adjusted so that all workers are paid a living wage. Health and safety risks in all aspects of productions will need to be closely documented and accounted for to ensure worker knowledge and proper procedures in the event of an emergency. Rigorous testing and risk assessment of all machinery and development processes will need to take place.

REID stores data after a run, and no personal information will be required in the user interface portion of the software development. This will ensure privacy of all users. At most, the date and test number will be recorded for record keeping purposes of the device to ensure quality across all tests and maintenance consistency. Anyone implementing this device into their company or storefront will be discouraged from asking for personal data from users.

Being transparent in a device's capabilities should be at the forefront of ethical considerations. Engineers should not lie about what their product does in order to get more consumer purchases. The features, limitations, and benefits of REID will be clearly labeled and openly discussed with purchasers in order to properly market the product and ensure what is being purchased is as expected. Deceptive marketing practices will never be encouraged.

In order to constantly improve the product and ensure long-term marketability, REID should have a user forum for feedback, questions, and concerns pertaining to the product. This will ensure both customer loyalty and accountability on the part of the manufacturer. In addition, any product will always be able to be improved and user feedback will only help to realize those goals even faster.

4.9 Sustainability Constraints

When considering sustainability of any product, there are many factors to consider. A large part of this is material selection and the efficiency of what's chosen in many aspects. Environmental impact has already been discussed, so other considerations will be discussed.

Choosing materials that are recycled, biodegradable, or renewable should be prioritized when making a product. 3D printing materials that fit this requirement to the best of technology that exists now should be used. Thankfully 3D printing is known for minimizing the amount of resources used, however energy consumption of 3D printers needs to be improved. Gas emissions from this portion of the production will also need to be considered and minimized. In addition, ensuring that the utilization of resources such as water and energy outside of 3D printing will need to be accounted for and implemented.

When packaging REID, environmentally friendly yet sturdy packaging will need to be used. As the environmentalist movement is making great strides in this regard, sourcing packaging that meets this requirement should not be an issue. It will need to be recyclable and biodegradable, as well as ensuring what is used is efficient enough that the amount used can be minimized to reduce packaging waste.

Sourcing from manufacturers that practice sustainability and good ethics will be prioritized. These sources will need to have a good history of transparency with consumers and good record keeping for traceability of every product we procure from them.

Planning for the long-life of any product should be a designer's goal. Single-use products are incredibly wasteful and should be avoided if possible. Life cycle assessments should be conducted in order to properly assess the impact of a product throughout its entire lifecycle, which includes the raw material extraction to disposal of the product. Toxic substances should be avoided that can release harmful chemicals into the environment once the product is disposed of. The end-of-life of the product will need to be accounted for, as it should be recyclable or have a proper disposal process. If any of the parts can be reused, all the better.

Educating the user on the specifications of the device will be needed. This includes its energy efficiency, recyclability, and proper usage to ensure as long as a life as possible for the product. In addition, providing the forum that was discussed earlier for constant improvement of the product can contribute to its longevity and sustainability.

If the product is advertised as sustainable, third-party certifications should be sought out and placed on marketing in order to validate any claims the company makes. This will ensure trust in the product and will provide the designers with better guidelines to making sustainable products.

5 Comparison of ChatGPT with other Similar Platforms

ChatGPT Analysis

When comparing something to its similar competitors, an analysis of the original must be done. ChatGPT is an amazing natural language processing tool that is driven by AI. It is better than most chatbots available and enables the user to have human-like interactions. It can answer questions and assist with basic language-based tasks, such as composing emails or resumes. It can answer questions related to code, science, and mathematics but has been unreliable in doing so. Its last information update was in January 2022, and thus does not have any updated information on world events past that point.

The technology behind ChatGPT is Large Language Model(LLM) technology. LLMs have proved that they play an important part in Artificial Intelligence-based technologies. Many LLM's are used for their capabilities in language processing and vast amounts of data that they can use to formulate a well written, human-like, response. The version of the model ChatGPT uses was developed by OpenAI, and is labeled as GPT-3.5. OpenAI has since stopped updating the model of its free version supposedly in order to turn profit, and an updated GPT-4 is used commonly in paid versions of alternative AI conversation bots. The GPT-3 model is seen rarely and is typically used in tandem with other AI tools or search engines.

At the base of an LLM is a neural network. A neural network is a machine learning model composed of many interconnected neurons, each of these being simple mathematical functions that process input data. The strength of connections between neurons is represented by numerical weights, determining how the output of one neuron can be determined as the input to another. Neural networks can vary in size, in the case of LLMs, the network would be very large containing millions of neurons and billions of connections, each with its own weight.

With the LLMs the program can perform calculations on the input to decide the output. Instead of having the instructions set in stone for the model to use, an algorithm is used to review the large volume of existing data to then actually define the model. As such, the human programmers are not the actual ones building the model, instead they build the algorithm that then builds the model.

When analyzing an LLM, programmers define the model's architecture and construction rules, but the model itself generates neurons, their connections, and the weight assigned to these connections during a process called "training".

During training the model follows the instructions to then define these itself. The training involves feeding the model large amounts of text data, and over time, through trial and error and constant comparison of the output to its input, the model is able to continually improve its text generation. With sufficient computing resources and data, the model can produce text that is near indistinguishable from human writing.

ChatGPT is a language learning model, and thus has features that reflect that. It can solve problems it's not explicitly trained on, hence the mathematical and coding capabilities. This ability is called zero-shot learning. In addition to this, if the AI doesn't know how to solve a problem, it can work out a solution to it based on a few examples. This mostly pertains to the language learning portion of the processing tool, as it bases the next words based on the previous examples it's given. This is a large part of the language learning model and has been essential in the success ChatGPT faces today.

The question answering feature of ChatGPT has been notably better than simply searching a question in a search engine. It produces well-tailored responses to questions and enables the user to not search the internet for the same question that has been reworded several times. Many people have turned to it for retrieving faster answers to more complex questions that would take longer to search themselves in the more common search engines.

The code generation of ChatGPT has surprised computer scientists and researchers alike. While it is very good and can provide working code for many languages for basic applications or problems, it is notoriously not to be relied on and meant to be an assistive tool.

As has been hinted at above, ChatGPT has its limitations. Even when asked questions it cannot possibly know the answer to, it gives its best attempt at providing a response, whether it be fake or simply wrong. For this reason, many people have gotten into scandals for relying on ChatGPT for answers that were supposedly true but upon simple search engine verification did not track.

The responses that are provided by ChatGPT are responses that sound right and are right a lot of the time, but there is no guarantee that the answer will actually be correct. No predetermined responses are used, instead the responses are created at the time of generation for each response. However, the information within LLMs is confined to their training data, which may be incomplete, incorrect, or outdated. For instance, ChatGPT's knowledge is limited to data available until January 2022, as it states itself, and it cannot access private or non-public documents, which can be crucial for many business applications. Many users may not know this and create a query requesting a response that would utilize information that is after the available data date. So the model can provide information that would have been the best response before or during the available data date but is outdated now.

Google Bard

Another LLM that has come out in recent times is Google Bard. Google Bard is an AI chatbot designed to mimic human conversations using natural language processing and machine learning. When the model originally came out it utilized Google LaMDA. LaMDA, which stands for Language Model for Dialogue Applications, is a family of conversational LLMs developed by Google AI. LaMDA is trained on a massive dataset of not only text but code as well. It can be used to complete many of the same tasks that ChatGPT is capable of accomplishing.

Unlike its initial use of Lambda, Bard has since upgraded to Google's advanced Palm 2 language model, which excels in common-sense reasoning, logic, and speed when compared to previous models.

PaLM 2

PaLM 2 is the next-generation LLM developed by Google AI. As a LLM successor it is significantly more powerful and capable. PaLM 2 was trained in similar manners to its predecessors including training with scientific and mathematical data, as well as text in over 100 languages. This gives PaLM 2 a wide range of knowledge and abilities. Google is currently working to make PaLM 2 more accessible to researchers and developers. The PaLM API is a cloud-based service that allows developers to access the power of PaLM 2 through a simple programming interface.

As we have discussed, it is known that ChatGPT's access to information is limited to the dataset it was trained on, which was last updated in 2021. This means that ChatGPT may not be able to provide accurate or up-to-date information on topics that have changed since then. Bard, on the other hand, has access to the real-time internet, which means that it can provide more up-to-date information on a wider range of topics. Bard can also access and process information from a variety of sources, including news articles, academic papers, and social media.

HuggingChat

Another AI chatbot is HuggingChat which utilizes the BLOOM LLM. BLOOM is an advanced language model with 176 billion parameters. It's trained on a vast dataset of text and code and is one of the world's largest and most powerful models. BLOOM can generate text, translate languages, create creative content, and provide informative answers like many other LLM based chatbots. It's multilingual, trained in 46 languages and 13 programming languages making it one of the most multilingual and versatile LLMs in the world. It continuously updates its knowledge, ensuring the latest information for up-to-date answers. Additionally, BLOOM is open source, offering its code freely for anyone to use and modify, promoting transparency and accessibility compared to proprietary models.

WriteSonic

WriteSonic is an AI tool that specializes in its marketing applications, a common use of ChatGPT. It produces optimized search engine content for blogs and webpages in addition to writing ads, emails, product descriptions, and posts for social media. It’s known for its long-form content creation that is high quality and akin to ChatGPT, as it uses models that were later developed by OpenAI. However, it is known to forget its tonal queues that users give it as well as not properly utilize previous instructions it's been given when generating new content. In addition, it has an odd pricing plan that is required after a certain word count. While it is cheaper than other AI writing tools, it cannot compare to the free, unlimited writing feature that ChatGPT offers.

Bing AI

BingAI is an interesting platform because it incorporates images into its AI chat features. It utilizes OpenAI's GPT-4 to power its AI search engine capabilities, which is considered a next generation LLM that is more powerful than ChatGPT's GPT-3.5. In addition to this, it uses Dall-E 2, which gives it its text to image capabilities. This gives it the unique multimodality that isn't involved in many AI search engines to date. On top of all of this it provides up to date results and includes cited sources to ensure credibility in its answers while remaining an entirely free platform. To its detriment, there is a limited number of prompts a user can make per session and the responses may be slow. Despite offering citations for its sources, it can still provide inaccurate information just like any other AI search engines.

Claude

Anthropic, a company supported by Google, has developed an AI called Claude that was designed using AI principles to ensure it provides honest and harmless answers while remaining helpful. It has two versions, called Claude Instant and Claude 2. Claude 2 is, obviously, more powerful and excels at a wide range of tasks. These can include dialogue as well as "creative" content generation and detailed instructions. Clause Instant, as named, is faster and cheaper. It excels in casual dialogue, text analysis, summaries, and document analysis and comprehension. If a user is skilled at prompting each model can still be used well to satisfy their individual needs. Additionally, it can be used to create downstream applications through its API. Claude is recommended over ChatGPT for specific applications, including deep understanding of technical content and generating optimized code. However, ChatGPT is still more reputable at most other tasks that the majority of the population requires with its language model.

Perplexity

Also utilizing OpenAI's already generated models, Perplexity AI is reputed as a ChatGPT alternative. Its free versions are powered by GPT-3, ChatGPT's older model. While ChatGPT's UI is very basic and somewhat clean, Perplexity boasts a minimalist, dark-themed interface that is desirable to most computer users today. Perplexity was created in order to solve the notorious problems of ChatGPT, namely its authenticity complications and copyright problems. It also cites its sources like Bing's AI chatbot and allows the user to fine-tune their searches by narrowing down these sources. The alternative to its free version is the Pro version that is powered by GPT-4. This version comes with a "copilot" that asks clarifying questions to guide the AI in its search for answers and find the best one for the user.

ChatSonic

Similar to most of the AI bots listed above, ChatSonic is branded as an alternative to ChatGpt and is geared towards content creation and creative tasks. The latest version is powered by GPT-4 as well as Google's search engine. Due to this, it can give you up-to-date information unlike ChatGPT's need to have knowledge updates. ChatSonic gives conversational, multi-moded replies and customized answers based on avatars. Some have reviewed the UI of this tool as complex and saturated, unlike ChatGPT's simple and straightforward approach. The conversations have been deemed to be quite slow and the AI can lose its focus on the topic after enough prompting. While it is branded to be a free alternative to ChatGPT, it has a limit of ten thousand words per month. To remove this limit, the price of a subscription must be paid.

Poe

Poe was created as an all-encompassing AI chatbot. It incorporates many large language models such as GPT-3.5-Turbo, GPT-4, Claude +, LlaMA 2, PaLM, and more. It was developed by Quora, and the goal for it was to have the benefits of most existing chatbots today in one system. It is notably fast with an easily understandable UI that can provide quick, accurate answers to questions. The idea behind this is that questions are passed through multiple LLMs and answers are given back from each one. A curious feature of Poe is that it allows the user to create personalized chatbots simply through initial prompts. Like many other AI software, there is a free version with notably less features than the premium version. The premium offers accessibility to all the available AI models without word or question limits.

Pi

Pi, which cleverly stands for "Personal Intelligence", is an AI assistant that was designed by Inflection AI. Its goal is to cater itself towards each user's unique interest and is branded as supportive, smart, and always available. It's oriented towards smartphone usage and is available on many of the most popular social media platforms, such as Instagram, Facebook, and WhatsApp. It even went the extra mile to develop its own iOS app while still being available on its website. Akin to virtual assistants such as Google or Siri, it features comforting voices to allow users to interact with it verbally. Despite all of these features, it is known to "hallucinate" and can have difficulty correctly answering complex questions. It has other languages available, but struggles with anything that isn't English. Like ChatGPT, it has knowledge updates and is even more up to date than its comparison counterpart, having knowledge from events before November 2022. Much to its detriment, Pi is only available to Apple users and the Android phone users must wait until a new app is developed.

Amazon CodeWhisperer

Branded as a coding assistant, Amazon CodeWhisperer has extensive training in the art of open-source code as well as code hosted in Amazon servers. It helps with applications such as coding recommendations and security checks. Amazon CodeWhisperer is more geared towards users who work with Amazon services, but it can also be used in IDEs such as JupyterLab and VS Code. It is reputed to work exceedingly well with more popular codes such as Python, Java, and JavaScript. It is a free, internationally available platform. It also provides citations for its generated code suggestions in order to enhance security.

Jasper AI

Jasper AI is geared towards marketing, SEO applications, and related fields. It's designed by the company Jasper and is an AI platform for businesses that is conversational. It assists in content creation tasks, varying from writing blog articles to writing love letters to that special someone. It's powered by multiple LLM models, such as OpenAI's GPT-4, Claude, and Google's models. It claims to learn and adapt to the user's voice to maintain tone consistency across their brand. It operates using templates that are designed for 50 different use cases and can help quickly generate complete, presentable content for a diverse array of applications. It can understand more than 30 languages, to allow for marketing campaigns in multiple countries. As it is geared towards content creation and not technical questions, it struggles with higher order concepts. Its replies require fact-checking and have been reviewed to be generic and repetitive, which is a concern with a template-based platform. There is no free version of this AI, which lowers it on the scale of usable LLM-based search engine chatbots.

10 Administrative Content

10.1 Process

1. Open the housing lid.
    a. Ensure that little to no contaminants (dust, skin oils, etc.) are present on the sample stage.
    b. Clean the sample stage if contaminants are present.
2. Load the sample into the chamber by placing it into the center of the rotation stage and closing the lid to ensure ambient light will not interfere.
3. Initiate the test sequence by pressing a button on the outside of the housing.
4. The fluorescence process will begin.
    a. The green LED will turn on and illuminate the sample, causing it to fluoresce if it's a real ruby.
    b. The emitted light from the ruby will travel through the fiber and will be analyzed via the spectrometer.
    c. Text will be displayed on the screen that indicates whether the sample passes this phase of the characterization.
    d. Whether the sample passes this test or not, the procedure will continue.
5. The dichroscope test will begin.
    a. The green LED will shut off and the white LED will turn on.
    b. The light reflected into the dichroscope would be focused onto the spectrometer, where if two distinct peaks are present then the sample passes the test.
    c. Repeat for three angles, labeled "Trial" and I, II, and III. If the ruby passes at least two of the three trials then it passes the whole test.
    d. Text will be displayed on the screen that indicates whether the sample passes this phase of the characterization, with individual trials included.
    e. Whether the sample passes this test or not, the procedure will continue.
6. The individual test and trial results will be displayed clearly on an external monitor. Specific data will be available as well.
7. An overall consensus on whether the ruby is synthetic, natural, or fake will be displayed in large letters.
8. The user will be given an option to save the data to a folder.
9. The trial is complete and on-screen text will indicate that the user is able to remove the ruby from the housing.
    a. The data from the previous run will not clear until the user manually does so or a new run begins.
    b. If the previous run data was not saved, the user will be prompted to save it before starting a new run. Nothing displays if the previous data was saved.

10.2 Budget

To complete this project it will cost approximately $1,168.35 as seen in Table 5.1. These prices are approximate as some of the specifications of the products might change. This project will have 3 main components that will be included into the budget. Including the Spectrometer, the Dichroscope, and the testing box. For each component of the project there will be different parts. The spectrometer will need a light source, a multimode fiber, two spherical lenses, a diffraction grating, a detector, and a green laser. The Dichroscope will need slits, a camera, calcite rhombus, glass prism and a display glass. Lastly, the testing box will need a motorized rotation stage, two types of rubies, glass, and white light source.

Component	Price
Spectrometer Materials:	
Single-mode Fiber	$10.00
Spherical Lens 2x	$200.00
Grating	$134.00
Pi Camera	$50.00
Green LED	$2.04
Raspberry Pi Module	$19.99
Dichroscope:	
White LED	$1.56
Beamsplitter	$46.00
Calcite Rhombus	$38.00
Glass Prisms	$57.00
Mirrors	
Testing Box:	
Motorized Rotation stage	$17.99
Two types of rubies	$200.00
	$1,168.35

10.3 Initial Project Milestones

These next two semesters we have a total of 7 big assignments. This semester will be the design portion of our project and will have three major assignments. One being a divide and conquer assignment due on September 15th, and a halfway checkpoint on November 3rd to have 60 pages completed and finally a 120 page final report due December 5th. Throughout the process of getting this final report done we will be meeting bi-weekly and occasionally more the closer we get to deadlines to ensure we are keeping our progress consistent. Our group will be meeting various times for each big assignment. For the Divide and Conquer assignment we will be meeting on September 14th to finalize our draft, on September 19th we will meet for the Divide and Conquer meeting that will be held with our professors, on September 28th we will meet to finalize the publish to our website as well as discuss progress on overall research. Our next big assignment is the 60 page turn in, for this we will split it into two parts and meet on October 17th to compile a 30 page draft, then again on November 2nd to compile and finalize the 60 page draft, then we will have a meeting on October 7th with professors to discuss the feedback for the draft, and lastly for this assignment we will meet on October 14th to finalize publication to our website. For the final report we will meet on November 21st to compile a 90 page draft and then meet again on December 1st to compile the last 30 pages of the draft to finalize the report.

For the spring semester we will have 4 big assignments. This is the building portion of the project where we will put all the research together to build the 2-D ruby laser printer. This semester will consist of a Middle term demo, final presentation, showcase, final report. The showcase will also include a summary and video. The final report consists of a website, peer review and exit interview. During this semester we will meet weekly to discuss progress on individual sections. Starting in February we will start to combine the individual sections into a demo.

#	Task	Start	End	Status	Responsible
Senior Design I					
1	Ideas	08/21/2023	09/08/2023	Completed	Group
2	Project Selection and Role Assignments	08/21/2023	09/15/2023	Completed	Group
Project Report					
3	Divide and Conquer	08/28/2023	09/15/2023	In Progress	Group
4	Table of Contents	09/18/2023	10/01/2023	In Progress	Group
5	60 Page Document	09/18/2023	11/03/2023	In Progress	Group
6	90 Page Document	09/18/2023	11/21/2023	In Progress	Group
7	120 Page Document	09/18/2023	12/05/2023	In Progress	Group

Research, Documentation, & Design					
8	Laser Acquisition	09/01/2023	09/22/2023	In Progress	Brianna/ Isabelle
9	Ruby Trigonal Structure	08/30/2023	09/22/2023	Researching	Isabelle
10	Ruby Fluorescence Spectra	08/30/2023	09/22/2023	Researching	Brianna
11	Spectrometer Schematic	09/18/2023	09/30/2023	Researching	Brianna/ Brandon
12	Dichroscope Schematic	09/18/2023	09/30/2023	Researching	Isabelle
13	Interlock System Schematic	09/18/2023	09/30/2023	Researching	Atman
14	PCB Layout	09/18/2023	09/22/2023	Researching	Atman
15	Recording & Data Abstraction	10/01/2023	11/01/2023	Researching	Group
16	Power Supply	10/01/2023	11/20/2023	Researching	Atman
17	Housing	10/01/2023	11/20/2023	Researching	Brandon
18	Motorized Rotation Stage	10/01/2023	11/20/2023	Researching	Brianna/ Isabelle
19	Lens Design - Spectrometer	09/18/2023	11/20/2023	Researching	Brianna
20	Lens Design - Dichroscope	09/18/2023	11/20/2023	Researching	Isabelle
21	**Order & Test Parts**	10/31/2023	12/01/2023	Researching	Group
Senior Design II					
22	Build Prototype	12/01/2023	01/01/2023		Group
23	Testing & Redesign	TBA	TBA		Group
24	Finalize Prototype	TBA	TBA		Group
25	Peer Presentation	TBA	TBA		Group
26	Final Report	TBA	TBA		Group
27	Final Presentation	TBA	TBA		Group

Appendix A Copyright Permission

Images provided in section 3.3.2 and section 3.3.3 Strategic Components and Part Selections are governed by one of the following:

- Raspberry Pi 4 B

Apache License 2.0 Version 2.0, January 2004 https://github.com/leswright1977/

Creative Commons (CC) BY-SA 4.0 Deed Attribution-ShareAlike 4.0 International.

Images provided in section 6 Electrical Supply / Components are governed by one of the following:

- Diffraction grating spectroscope.

Apache License 2.0 Version 2.0, January 2004

https://github.com/leswright1977/PySpectrometer/tree/main/media

Appendix B / Sources

1. *Alternate Wavelengths for CO2 Lasers.* Novanta Corporation, 2021.

2. Stephen Lowry, P.D., Thermo FisherScientific, Madison, WI, USA, *Analysis of Rubies and Sapphires by FT-IR Spectroscopy.* 2008.

3. Sun, Z. and H. Breitzmann. *Flame-Fusion Synthetic Ruby Boule with Flux Synthetic Ruby Overgrowth*. 2014 [cited 2023 September 14]; Available from: https://www.gia.edu/gems-gemology/fall-2014-labnotes-flame-fusion-synthetic-ruby-boule-flux-synthetic-ruby-overgrowth.

4. Dhameja, A.K. *Identification of Rubies*. 2016 9/14/2023; Available from: https://nimsacademy.wordpress.com/2016/07/04/identification-of-rubies/#:~:text=Double%20Refraction%20Test,of%20refraction%20in%20a%20polariscope.

5. *Identification By Double Refraction & Pleochroism*. 9/14/2023; Available from: http://www.gemstones-guide.com/Identification-Double-Refraction-Pleochroism.html

6. *Ruby Crystal Fluorescence*. 2020 June 15, 2020 [cited 2023 September 14]; Available from: https://physicsopenlab.org/2020/06/15/ruby-crystal-fluorescence/#:~:text=Abstract%20%3A%20ruby%20has%20a%20red,appears%20as%20a%20single%20line.

7. Heiman, D., *Spectroscopy of Ruby Fluorescence.* Northeastern, 2021.

8. Muhlmeister, S., et al., *Separating Natural and Synthetic Rubies on the Basis of Trace-Element Chemistry.* Gems & gemology, 1998. **34**(2): p. 80-101.

9. Ferguson, James; Brewster, Sir David (1823). Lectures on select subjects in mechanics, hydrostatics, hydraulics, pneumatics, optics, geography, astronomy, and dialling. Vol. 2 (Third ed.). Edinburgh: Stirling & Slade, and Bell & Bradfute. pp. 333–336. Retrieved 12 November 2012.

10. Pornwilard M.-M., et al. *Geographical origin classification of gem corundum using elemental fingerprint analysis by laser ablation inductively coupled plasma mass spectrometry*. International Journal of Mass Spectrometry. 2011. 306(1): pp. 57-62.

11. Shigley, James E. *A review of current challenges for the identification of gemstones*. Geologija. 2008. Vol. 50. No. 4(64). pp. 227–236.

12. Emmett, John L. *The role of silicon in the color of gem corundum*. Gems & Gemology. 2017. Vol. 53, No. 1, pp. 42–47.

13. Breeding, Christopher M., et al. *Developments in gemstone analysis techniques and instrumentation during the 2000s*. Gems & Gemology. 2010. Vol. 46, No. 3, pp. 241–257.

14. Calligaro, T., et al. *Provenance study of rubies from a Parthian statuette by PIXE analysis*.
Nucl. Instrum. Methods B, 136 (1998), pp. 846-850.

15. Rankin, A.H., et al. *Chemical fingerprinting of some East African gem rubies by laser ablation ICP-MS*. J. Gemmol., 28 (2003), pp. 473-482.

16. Joseph, D., et al. *Characterization of gem stones (rubies and sapphires) by energy dispersive X-ray fluorescence spectrometry*. X-ray Spectrom., 29 (2000), pp. 147-150.

17. Sanchez, J.L., et al. *Micro-PIXE analysis of trace element concentrations of natural rubies from different locations in Myanmar*. Nucl. Instrum. Methods B, 130 (1997), pp. 682-686.

18. Harmon, R.S., et al. *LIBS analysis of geomaterials: geochemical fingerprinting for the rapid analysis and discrimination of minerals*. Appl. Geochem., 24 (2009), pp. 1125-1141.

19. Keulen, Nynke, et al. *Formation, origin and geographic typing of corundum (ruby and pink sapphire) from the Fiskenæsset complex, Greenland*. Lithos., Volumes 366–367, August 2020.

20. Sutherland, F. Lin, et al. *Sapphire-ruby characteristics, West Pailin, Cambodia: clues to their origin based on trace element and O isotope analysis*. Aust. Gemmol., 23 (2008), pp. 329-368.

21. Sharp, Z.D. *A laser-based microanalytical method for the in-situ determination of oxygen isotope ratios of silicates and oxides*. Geochim. Cosmochim. Acta, 54 (1990), pp. 1353-1357.

22. Sutherland, F. Lin, et al. *Advances in Trace Element "Fingerprinting" of Gem Corundum, Ruby and Sapphire, Mogok Area, Myanmar.* Minerals **2015**, *5*(1), 61-79.

23. Calligaro, T.; Poirot, J.P.; Querré, G. *Trace element fingerprinting of jewelry rubies by external beam.* J. Nucl. Instrum. Methods Phys. Res. **1999**, B150, 628–634.

24. Mittermayr, F.; Konzett, J.; Hausenberger, C.; Kaindl, R.; Schmiderer, A. *Trace element distribution, solid- and fluid inclusions in untreated Mong Hsu rubies*. Geophys. Res. Abs. **2008**, 10. EGU-A-1076.

25. Keulen, N.; Kalvig, P. *Fingerprinting of corundum (ruby) from Fiskenaesset, West Greenland*. GEUS Geol. Surv. Den. Greenl. Bull. **2013**, 28, 53–56.

26. Mokgalaka, N. S., et al. *Laser Ablation Inductively Coupled Plasma Mass Spectrometry: Principles andApplications*. Applied Spectroscopy Reviews. 41: 131–150, 2006.

27. Patnaikuni, Patnaik et al. *A Comparative Study of Arduino, Raspberry Pi and ESP8266 as IoT Development Board*. International Journal of Advanced Research in Computer Science; May/Jun2017, Vol. 8 Issue 5, p2350-2352.

28. Thothadri, Madhavan. *An Analysis on Clock Speeds in Raspberry Pi Pico and Arduino Uno Microcontrollers*. American Journal of Engineering and Technology Management,
2021; 6(3): 41-46.

29. Maksimović, Mirjana et al. *Raspberry Pi as Internet of Things hardware: Performances and Constraints*. Proceedings of 1st International Conference on Electrical, Electronic and Computing Engineering IcETRAN 2014, Vrnjačka Banja, Serbia, June 2 – 5, 2014.

30. Karvinen, Tero et al. *Make: Sensors: A Hands-On Primer for Monitoring the Real World with Arduino: A Hands-On Primer for Monitoring the Real World with Arduino and Raspberry Pi*. Maker Media, Inc., 2014.

31. Noor, Nur Qamarina Mohd et al. *Arduino vs Raspberry Pi vs Micro Bit: Platforms for Fast IoT Systems Prototyping*. Open International Journal of Informatics (OIJI), Vol. 6 Iss.1 (2018).

32. Kimmo Karvinen, Tero Karvinen. *Getting Started with Sensors: Measure the World with Electronics, Arduino, and Raspberry Pi*. Maker Media, Inc., Aug 14, 2014.

33. Hadwan, Hamid Hussain et al. *Smart Home Control by using Raspberry Pi & Arduino UNO*. International Journal of Advanced Research in Computer and Communication Engineering, Vol. 5, Issue 4, April 2016.

34. Hobbs, S. W. et al. *Evaluating low-cost spectrometer designs for utility in reflectance and transmittance applications*. International Journal of Remote Sensing. Volume 40, 2019 - Issue 2.

35. Deshmukh, Sanjay D. *Building a Low-cost, Low-Power and Portable Spectrophotometer for Chemical Analysis*. Solid State Technology, Volume: 64 Issue: 2 Publication Year: 2021.

36. Antela, Kevin U. et al. *Development of an automated colorimeter controlled by Raspberry Pi4*. Anal. Methods, 2023, **15**, 512-518.

37. Myers, David L. et al. *An Open Platform Microcontroller-Based Laser Refractometer*. J. Chem. Educ. 2023, 100, 3, 1257–1262.

38. Park, Sanghoon et al. *Development of a compact all-in-one chemical sensing module for in situ detection of fine dust components based on spark-induced plasma spectroscopy*. Measurement, Volume 192, 31 March 2022.

39. Gräb, Patrick et al. *Low-cost Spectroscopy: Experiments in Various Spectral Ranges*. World Journal of Chemical Education, 2021, Vol. 9, No. 4, 144-151.

40. Hobbs, S. W. et al. *Developing a spectral pipeline using open source software and low-cost hardware for material identification*. International Journal of Remote Sensing, Volume 41, 2020 - Issue 7.

41. Feister, Scott et al. *Control systems and data management for high-power laser facilities*. High Power Laser Science and Engineering, Volume 11, 2023, e56. DOI: https://doi.org/10.1017/hpl.2023.49

42. America, G. I. of. (n.d.). *GIA ID100®*. GIA iD100 Gem Testing Device. https://discover.gia.edu/id100#:~:text=Rather%20than%20using%20UV%20light,if%20a%20stone%20is%20natural/

43. *Cube beamsplitters*. Cube Beamsplitters | Edmund Optics. (n.d.). https://www.edmundoptics.com/f/cube-beamsplitters/12428/

44. *Dichroscope guide for Gemologists*. International Gem Society. (2023, March 9). https://www.gemsociety.org/article/the-dichroscope/

45. *Encyclopedia of Crystallographic prototypes*. Trigonal Lattice. (n.d.). http://www.aflowlib.org/prototype-encyclopedia/trigonal_lattice.html#:~:text=The%20trigonal%20crystal%20system%20is,%2C%20γ%3D120◦.

46. Encyclopædia Britannica, inc. (n.d.-a). *Optical crystallography*. Encyclopædia Britannica. https://www.britannica.com/science/optical-crystallography

47. Encyclopædia Britannica, inc. (n.d.-b). *Pleochroism*. Encyclopædia Britannica. https://www.britannica.com/science/pleochroism

48. *Garnet*. Earth Sciences Museum. (2013, October 9). https://uwaterloo.ca/earth-sciences-museum/resources/detailed-rocks-and-minerals-articles/garnet#:~:text=Garnets%20generally%20produce%20symmetrical%2C%20cube,diamond%20shaped%20(rhombic)%20faces.

49. *Gem Tester II*. Presidium Website. (n.d.). https://www.presidium.com.sg/product/colored-gemstone-testers/gem-tester-ii

50. Hughes, R. W. (n.d.). *Optic character/sign with the jeweler's refractometer*. Ruby. https://www.ruby-sapphire.com/index.php/about/10-articles/821-crystal-optics

51. *Introduction to optical prisms*. Edmund Optics. (n.d.). https://www.edmundoptics.com/knowledge-center/application-notes/optics/introduction-to-optical-prisms/

52. Luna, J. C. (2023, August 17). *The top 10 CHATGPT alternatives you can try Today*. DataCamp. https://www.datacamp.com/blog/10-chatgpt-alternatives

53. *Non-polarizing cube beamsplitters (400 - 700 nm)*. Thorlabs, Inc. - Your Source for Fiber Optics, Laser Diodes, Optical Instrumentation and Polarization Measurement & Control. (n.d.-a). https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=754

54. *Plate beamsplitters*. Plate Beamsplitters | Edmund Optics. (n.d.). https://www.edmundoptics.com/f/plate-beamsplitters/12424/

55. *Principles of Birefringence*. Nikon's MicroscopyU. (n.d.). https://www.microscopyu.com/techniques/polarized-light/principles-of-birefringence

56. Spectroscopy of Ruby fluorescence - Northeastern University. (n.d.-a). https://web.northeastern.edu/heiman/3600/RUBY.pdf

57. L. (2023, September 8). *Gem Testers*. Quicktest. https://www.quicktest.co.uk/blogs/testing-diamonds-gemstones/a-lot-about-electronic-gem-testers#:~:text=Electronic%20refractometer%20(reflectivity%20meter)%2C,no%20waiting%20time%20between%20tests

58. *UV fused silica broadband plate beamsplitters (coating: 400 - 700 nm)*. Thorlabs, Inc. - Your Source for Fiber Optics, Laser Diodes, Optical Instrumentation and Polarization Measurement & Control. (n.d.-b). https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=4807&pn=BSN04

59. What are lenses? - ohio energy project. (n.d.-b). https://ohioenergy.org/wp-content/uploads/2019/08/5L13-Light-What-Are-Lenses-Teacher-Handout.pdf

60. Wikimedia Foundation. (2023a, August 29). *Pleochroism*. Wikipedia. https://en.wikipedia.org/wiki/Pleochroism

61. Wikimedia Foundation. (2023b, October 13). *Corundum*. Wikipedia. https://en.wikipedia.org/wiki/Corundum#:~:text=Structure%20and%20physical%20properties,-Crystal%20structure%20of&text=Corundum%20crystallizes%20with%20trigonal%20symmetry,surface%20roughness%20and%20crystallographic%20orientation.

62. Wikimedia Foundation. (2023c, October 13). *Corundum*. Wikipedia. https://en.wikipedia.org/wiki/Corundum#:~:text=Structure%20and%20physical%20properties,-Crystal%20structure%20of&text=Corundum%20crystallizes%20with%20trigonal%20symmetry,surface%20roughness%20and%20crystallographic%20orientation.

Wikimedia Foundation. (2023d, October 19). *Birefringence*. Wikipedia. https://en.wikipedia.org/wiki/Birefringence