DETERMINATION OF THE LIGHT TRANSFER PROPERTIES OF POLYACRYLAMIDE GEL USING VARIOUS LIGHT EMITTING DIODES

by

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I would like to acknowledge Dr. Dale Moore for the numerous contributions he made to this project. Without the use of his chemistry lab and equipment, many of the experiments would never have been performed. I am grateful for the time and ideas he contributed to this project. His chemical expertise provided the foundation of the polyacrylamide gel design.

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ABSTRACT

BEN DREW CRAVEY III
Determination of the Light Transfer Properties of Polyacrylamide Gel Using Various Light Emitting Diodes
(Under the direction of DR. PHILIP D. OLIVIER and DR. DALE E. MOORE)

The use of gels to emit or transfer light has been studied and experimented with mainly on the microscopic level of thin films. It is possible, however, to use a larger, on the order of inches, gel tube to transmit light from one place to another. In particular, this paper describes the light transfer properties of polyacrylamide gel through several different length and size tubes. A light emitting diode (LED) acts as the light source on one end of the gel tube, and its light is effectively transmitted through the polyacrylamide gel inside the tube similar to the way fiber optic cables transmit information. Through experimentation, it was determined that this polyacrylamide gel transmitted higher wavelengths of light more efficiently than lower wavelengths of light. This was determined by using red, white, and blue LEDs and measuring the spectral intensity at the output end of the gel tubes. Furthermore, the spectral intensity at the output decreases with an increase in tube length. This problem, however, can be partially solved by simply shielding the tube until the desired transmission length has been reached since the majority of the light escapes through the sides of the tube. Several applications including the automotive, military, and consumer industries are discussed as well as possible future experiments.

CHAPTER 1

INTRODUCTION

Numerous people desire a small, long-lasting, and flexible light source to illuminate certain areas. Due to limited space and oblique surroundings, people tend to spend a large majority of their time searching for objects in dark corners that escape the normal sources of light.

However, no innovative light source that illuminates the dark areas in which people tend to waste valuable time attempting to perform a task without light exists. Some people turn on existing lights, but frequently these lights do not fully illuminate all areas of the space with which the person is concerned. Additionally, many people tend to utilize the small flashlights on their key chains, but these devices must usually be held in order for them to operate. The existing lighting or handheld lights make it difficult to perform tasks in dim areas due to the light not being able travel around corners or to the use of a hand for proper operation, respectively.

Therefore, people need a well designed, flexible, lightweight, nontoxic, and long-lasting light source that will illuminate areas that existing lights do not reach. To satisfy this need, I began investigating several methods to transfer light from one place to another, particularly into tight spaces or into areas that have numerous corners. This research evolved into experimenting with gels and light emitting diodes (LEDs), which has led me to discover various light transfer properties of gels when illuminated by different colors of LEDs.

At first, the research and experimentation was concentrated on the idea of developing a gel that would emit light without the use of any type of physical light source, such as an LED. The experimental aspects of this initial concept consisted of developing several small samples of a polyacrylamide gel in the shape of circular cylinders. A voltage was then applied across the gel samples and the results were observed. Once it was determined that no illuminescent effect resulted from the charged gel, the focus of the project shifted back to research and brainstorming. As more research was accumulated, it became apparent that the chemical aspects of the current project far exceeded the scope of my chemical knowledge. Therefore, I decided to alter the project to one that utilized the polyacrylamide gel to transmit light from an existing light source to other areas.

The change in the scope of the project resulted in more studying, this time focusing more on fiber optics. Following the literature search, the next phase of experimentation centered upon forming the gels in a tube. Once a prototype gel tube was developed and tested, a larger size one was created to test the gel's ability to transmit light around corners. This proceeded to the experiment of producing several lengths of gel tubes of two different radii. The main experiment focused on determining the wavelength (color) of light the polyacrylamide gel transmitted most efficiently by changing the color of the LED's used in the light source. The experiment consisted of several smaller experiments to determine other transfer properties of the gel. All experiments are discussed in great detail in Chapter 3: METHODS and Chapter 4: RESULTS. It was at this time that further experimentation was halted in order to conclude the project for the class. If the opportunity arises in the future, additional experimentation will be completed. A description of possible future experiments is included in Chapter 5: DISCUSSION.

Literature Survey

[1] S.-C. Chang and Y. Yang, "Polymer gel light-emitting devices," *Applied Physics Letters*, vol. 75, pp. 2713—2715, Nov. 1999.

This article described the generation of luminescence from a polymer gel in a compact cell configuration. It highlighted a unique polymer gel light-emitting device (GLED) that consisted of a thin layer of a polymer gel sandwiched between two electrode/glass substrates. Furthermore, the article compared the emission spectrum of the GLED with the photoluminescence spectrum obtained from the polymer gel. Even though this article seemed relevant to this project, its focus on the microscopic level of thin films was not directly applicable.

[2] S. Sasaki and F. J. M. Schipper, "Coupled diffusion of segments and counterions in polyelectrolyte gels and solutions," *Journal of Chemical Physics*, vol. 115, pp. 4349—4354, Sep. 2001.

This article compared polyelectrolyte gels to polyelectrolyte solutions and revealed that the dynamical properties of chain segments and counterions are almost identical for the two. In this article, the authors also prove that coupling the dynamics of the polyelectrolyte segments and counterions is valid both for polyelectrolyte solutions and for the gel system. Again, this article focused too much on the chemical aspects of the gel and quickly surpassed my chemical knowledge. Therefore, this article contributed little to the development of the project.

[3] C. D. Jones, L. A. Lyon, and J. G. McGrath, “Characterization of cyanine dye-labeled poly(N-isopropylacrylamide) core/shell microgels using fluorescence resonance energy transfer,” *Journal of Physical Chemistry B*, vol. 108, pp. 12652—12658, Aug. 2004.

This article describes the investigation of the swelling behavior of the core component in poly(N-isopropylacrylamide) (pNIPAm) core/shell microgels via fluorescence resonance energy transfer (FRET). Several experiments involving photon correlation spectroscopy are described, and their results are explained. Although the title of this article appeared to be of interest to this project, the content of the article was far from the objective of this project.

[4] J. C. Palais, *Fiber Optic Communications*, 4th ed. Upper Saddle River, NJ: Prentice Hall, 1998.

This book supplies the reader with the information necessary to understand the design, operation, and capabilities of fiber systems. The book describes several subjects on the fundamentals on which fiber optic technology is based, including fibers, optics, communications, optic communications, and complete fiber optic communication systems. The construction of fiber optic cables is described, and their theory of operation is explained. This book contained much relevant material that was useful to the project. Understanding how fiber optics worked allowed me to understand how the LED’s light was propagating through the polyacrylamide gel tube. Additionally, this book described several applications of fiber optics that aided in the overall design of the polyacrylamide gel light.

[5] C. R. Paul, *Electromagnetics for Engineers*. Hoboken, NJ: John Wiley & Sons, 2004, pp. 245—247.

This book provides a brief summary of the theory of operation behind fiber optic cables. It provides several simple equations using the index of refraction and relative permittivity of the cable to calculate the angle at which the signal travels through the fiber optic cable. This book provided me with the information needed to determine the critical angle at which the LED would not transmit light through the polyacrylamide gel tube. Since the gel tube resembled a fiber optic cable with the exception that some of the light is transmitted through the sides of the tube, I was able to predict how the light would be transmitted through the tube.

[6] C. R. Paul, K. W. Whites, and S. A. Nasar, *Introduction to Electromagnetic Fields*, 3rd ed. Boston, MA: McGraw-Hill, 1998, pp. 573—575.

This book provided a description of different types of optical fibers and the advantages and disadvantages of each type. Furthermore, laser diode and light-emitting diode optical fibers were discussed. The theory of operation of optical fibers was also described. The information in this book aided my decision in the correct light source to use for the polyacrylamide gel light tube. Moreover, the book provided me with a better understanding of fiber optic cables, which are related to the gel light tube I was developing.

CHAPTER 2

PROJECT DESCRIPTION

Project Goals

Stemming from the main goal of determining how gels could be incorporated into electrical engineering to be used for practical purposes were many other goals associated with the project. The main purpose of which was to design a LED gel light that is flexible, lightweight, nontoxic, and long lasting. In order to accomplish this task, the basic properties of gels had to be explored, along with numerous applications of gels. Additionally, the design of a light source that evenly transmitted enough light to illuminate a specified area was necessary. Once a light source was developed, the objective of the project shifted to determining the light transfer characteristics of polyacrylamide gels using LEDs.

Design Criteria

In order to accomplish the goals described above, several design criteria had to be met. First, the product must be able to emit a sufficient amount of light that is evenly transmitted. Then, there must be an impedance match to allow for maximum transmission of light through the gel. Along with being flexible and lightweight, the product must be safe and useful in everyday life. Finally, the design of the product must be economical. The attainment of these design criteria was attempted using every means possible throughout this project.

CHAPTER 3

METHODS

Design Alternatives

Once a basic understanding of gels and their uses had been developed, it was decided that the main research and acquisition of new knowledge on this subject would be a direct result of first hand experimentation instead of reviewing previous work. Therefore, several ideas of an initial gel light emerged and each alternative considered.

Alternative One: CYALUME® Excitation

The first design involved using glow sticks made with CYALUME® technology as a light source and exciting the CYALUME® chemicals by applying a varying electric potential to them. Several questions were considered about whether the device, if electrically excited, would glow for longer periods or whether adding certain chemicals would result in a longer lasting glow. Once it was decided that chemical alterations of an existing product was not the ideal focus of this project, a second alternative was developed. A CYALUME® glowstick is shown in the following figure.

Figure 1: CYALUME® Glowstick

Alternative Two: Gaseous Polyacrylamide Gel

The idea of a gel filled with a gas or a chemical that emits light was the next alternative considered. In this design, a type of gel, most likely polyacrylamide, would be created and formed into a shape that would house gases or chemicals such as aluminum, gallium, phosphorous, arsenic, etc. Therefore, the gases would be emitting the light, not the gel itself. However, safety issues and chemical complexity in general led to the decision to develop more electrical engineering focused alternatives.

Alternative Three: Polyacrylamide Gel Excitation

Returning more to the engineering aspect versus the chemical aspect, combining a polyacrylamide gel with an electrical device became a clear forerunner as a plausible design from which to choose. This device involved covering an electrical component, such as a wire, with a type of polyacrylamide gel and using the electrical component to excite the illuminescent characteristics of the gel. After brief experimentation, it was determined that the gel would be better utilized as a transport mechanism rather than the light source. The following figure displays the concept of this alternative.

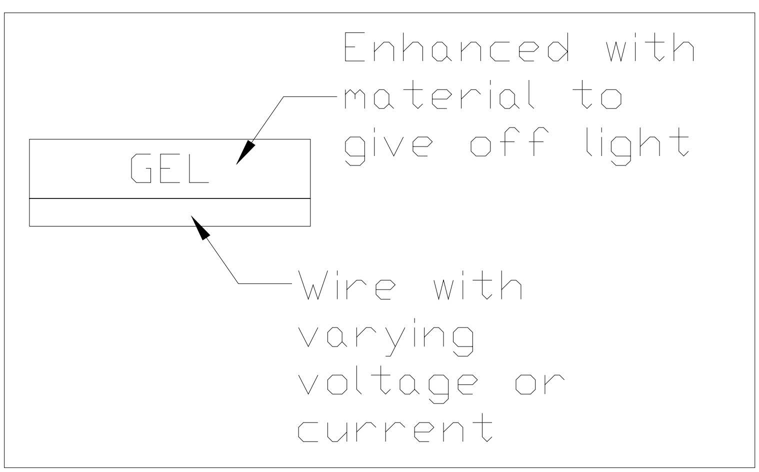

Figure 2: Polyacrylamide Gel Excitation Alternative

<u>Alternative Four: LED Enhanced Polyacrylamide Gel</u>

Based on the discovery mentioned with the previous alternative, a light emitting device (light emitting diode) was chosen as the source of light to be transported through the polyacrylamide gel over longer and/or curved distances. This design focused on using a simple electrical circuit to turn on a light emitting diode (LED) that would serve as the light source. This circuitry and LED would then be covered with the polyacrylamide gel, which would control the path of the light being emitted and direct it in certain directions. The gel would also provide the desired flexibility for the device with the exception of the area immediately surrounding the electrical circuit. The following two figures illustrate two general ideas of how this alternative would be implemented.

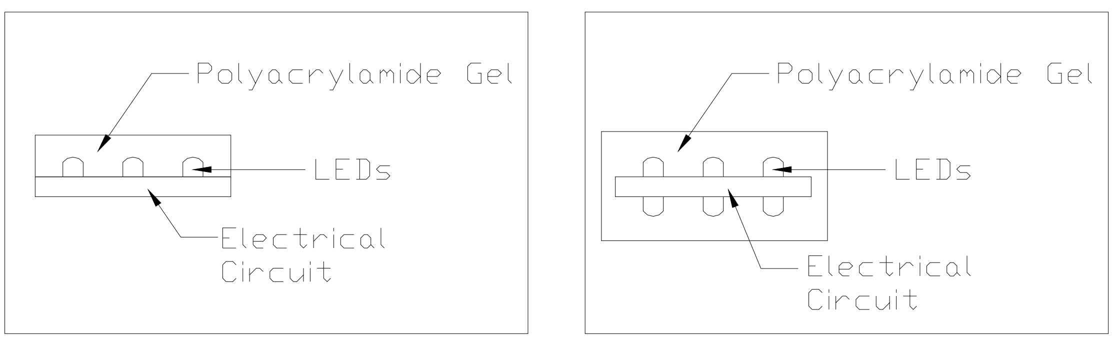

Figure 3: LED Enhanced Polyacrylamide Gel Alternative

<u>Selection of Design: LED Polyacrylamide Gel Light Tube</u>

Reviewing each design alternative and proceeding through sequential steps to determine the overall goal of this project, a final design emerged from the fourth alternative. A merger of electrical engineering and chemistry became the focal point of the experimentation process. The polyacrylamide gel would be enclosed in a plastic tube that could be formed to almost any shape so that difficult areas could be illuminated with the LED's light. The LED and electrical circuitry would be compact and attached to one end of the gel tube with the LED inserted into the tube, making a smooth connection with the gel. Once turned on, the LED's light would be transported through the gel tube to the other end, with some light being emitted out of the sides of the tube and some out of the tube's end. Now that an actual design had been developed, the main experimentation process to determine the light transfer properties of the polyacrylamide gel using various LEDs began. The following figure exhibits the final design for the LED gel light.

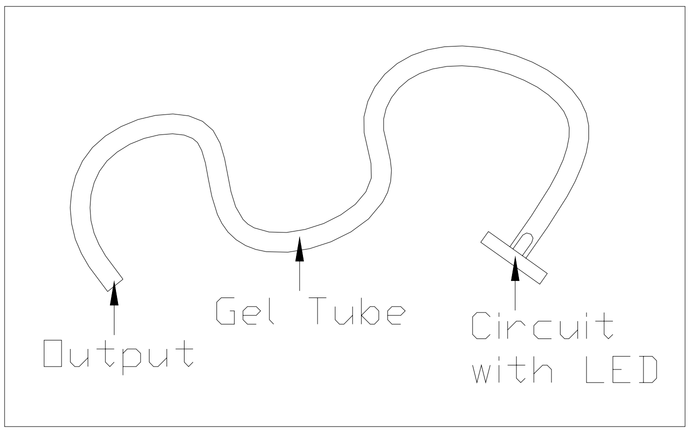

Figure 4: LED Polyacrylamide Gel Light Tube

Experiments

The experimental phase began as soon as the concrete plan of how to proceed was achieved. The experiments themselves were the focus of research for this project because little research on combining polyacrylamide gel and LEDs has actually been performed by others. There has been, on the other hand, much research of using polyacrylamide gel with thin films [1], polyelectrolyte solutions [2], and microgels [3]. These topics, however, were beyond the breadth of my personal chemical knowledge or did not directly apply to this project. Each experiment that was performed is outlined below, and all experiments refer to the final design described above with the exception of the last part of experiment one, which concerns alternative three. The results from each experiment are documented in Chapter 4: RESULTS.

Experiment One: Creation of Polyacrylamide Gel and Electric Excitation Test

The first experiment involved making a sample of polyacrylamide gel to determine if it would meet the design goals of the project. This experiment took place in Dr. Dale Moore's lab in the chemistry department at Mercer University. Therefore, laboratory safety procedures were reviewed and the proper precautions were taken while making the gel. For this initial experiment, two samples of polyacrylamide gel were formed in small beakers so that the material properties of the gel itself could be explored. Dr. Moore supplied the ingredients for the polyacrylamide gel, which are outlined below.

- Acrylamide, 97 % (C_3H_5NO)
- Bis-acrylamide (N, N-methylenebisacrylamide; $C_7H_{10}N_2O_2$)
- Water (H_2O)
- Rhodamine B ($C_{28}H_{30}N_2O_3$)
- Ammonium persulfate (APS; $(NH_4)_2S_2O_8$)
- Tetramethylethylenediamine (TEMED; $C_6H_{16}N_2$)

The formula called for 30 grams of acrylamide, 0.8 grams of bis-acrylamide, and 72 grams of H_2O to be mixed together to form a solution. Then, 7.5 milliliters of this solution were mixed with 7.5 milliliters of Rhodamine B to form a 15 milliliter solution. A small amount of APS was then dissolved with H_2O in a separate container, and a few drops of this solution were added to the polyacrylamide solution to aid the polymerization reaction. Finally, a few drops of TEMED were added to initiate the reaction so that the polyacrylamide gel would form. This solution yielded two samples of polyacrylamide gel in the shape of approximately a one-inch diameter cylinder with a height of approximately three eighths inches. These samples were then tested to ensure the polyacrylamide gel would meet the design goals and to determine if alternative three mentioned in the previous chapter would work.

Experiment Two: Creation of Polyacrylamide Gel Tube and Initial Tests

Once it was determined that the polyacrylamide gel possessed the desired properties for this project, a second experiment was conducted to make a light tube with the gel. A one-half inch clear plastic tube was used to contain the gel and mold it into the tube shape. A three-foot section of tubing was cut, along with several smaller four and five inch sections. Each of these sections of tubing were clamped vertically in Dr. Moore's chemistry lab. The same ingredients as used in the first experiment were used here with the exception of increasing the quantity of each ingredient since more gel solution was needed to fill the tubes. The amount of each ingredient from experiment one was approximately tripled to obtain the correctly scaled amount of solution. Two drops of APS were added for each ten milliliters of solution, and one drop of TEMED was added for each twenty-five milliliters of solution. Each of the tubes were corked at the bottom end, and the gel solution was carefully poured into them. The tubes were then allowed to stand several minutes until chemical reaction that transformed the solution into a gel had fully taken place. As the reaction was taking place, an LED was held at the end of one of the short sections of tubing to allow the gel to form smoothly around the face of the LED.

By forming the gel to the LED, it was possible to test the effect of how well the LED connected with the gel. The connection the LED made with the gel determined how matched the LED and the gel were, and a well-matched pair would eliminate reflections of the light at the connection point and transmit more light through the gel. Once the polyacrylamide gel tubes had formed, they were corked at each end to seal out air and taken to another laboratory so that the gel's transmission properties could be tested with various colors of LEDs.

As a continuation of experiment two, a red, white, and blue LED were each placed at one end of the three-foot length gel tube so that the light would be transmitted through the gel and illuminate the other end of the tube. The tube's effect on the light was observed. The approximate transmission distance was measured, and the approximate output intensity of each color LED that was visible to the eye was noted. The effect of matching the LED's shape with the gel was then tested with the shorter tubes. Light from each LED was transmitted through a tube with a formed fit for the LED and one without a formed fit. The effect of having a smooth connection for light transmission at the end of each tube was visible to the human eye in the form of increased brightness.

Experiment Three: LED Frequency Spectrum Analysis

The third experiment involved measuring the frequency spectrum of each of the LEDs emissions to determine the main wavelengths contained in each LED's light. This experiment was performed in the chemistry building at Mercer University using the FlouroMax-2 Spectroflourometer. A cover was placed over the instrument's light source since the LEDs were themselves a light source. Each different color LED was placed in the instrument one at a time and its frequency spectrum measured. Once the red, white, and blue LED's frequency spectrums were all measured, the results were observed and the main frequencies of the lights were recorded.

Experiment Four: Creation of Various Polyacrylamide Gel Tubes

Once it was determined that the polyacrylamide gel transmitted the light of different color LEDs different lengths, a fourth experiment was conducted to make more polyacrylamide gel tubes of different lengths and diameters. As in experiment two, a one-half inch clear plastic tube was used to contain the gel and mold it into the tube shape. Since a three-foot gel tube was already made, a two-foot and a one-foot section of the one half inch diameter tubing were cut to make two more tubes of shorter lengths. Additionally, a one-foot and a two-foot section of one fourth inch diameter tubing were cut to determine the effect of the thickness of the gel on the light transmission. Each of these sections of tubing were clamped vertically in Dr. Moore's chemistry lab. The same ingredients as used in the first experiment were used here with the exception of increasing the quantity of each ingredient since more gel solution was needed to fill the tubes. The amount of each ingredient from experiment one was increased approximately five times to obtain the correctly scaled amount of solution. Each of the tubes were corked at the bottom end, and the gel solution was carefully poured into them. The tubes were then allowed to stand for one week to ensure the chemical reaction that transformed the solution into a gel had fully taken place. Once the polyacrylamide gel tubes had formed, they were corked at each end to seal out air and taken to another laboratory so that the gel's transmission properties could be tested with various colors of LEDs.

Experiment Five: End of Tube Spectral Intensity Test One

Similar to the second experiment, this experiment involved shining an LED into one end of each tube and measuring the spectral intensity at the other end of the tube. The FlouroMax-2 Spectroflourometer was again used as the measurement device. First, the instrument was calibrated with a tube filled with polyacrylamide gel but no light source (LED) present. The spectral intensity at the output end of the one-foot, half-inch tube was then measured with the white LED shining into the input end of the tube. This process was repeated for the two-foot and three-foot tubes with the white LED. Then, the white LED was replaced by the red LED, and the spectral intensity at the end of each tube length was measured. Next, the blue LED was inserted and its spectral intensity measured for each length. Finally, the one-foot and two-foot, quarter inch diameter tubes were tested using the red LED for the input. Due to time constraints, only the red LED could be tested on the smaller diameter gel tube for this experiment.

Experiment Six: End of Tube Spectral Intensity Test Two

After it was determined that experiment five's results were contaminated with ambient light entering the measurement device, the experiment was performed again in more controlled conditions. The FlouroMax-2 Spectroflourometer was again used as the measurement device; however, the lights were turned off in the room and the hole the tube was inserted through on the instrument was sealed. Furthermore, a shield was placed around the end of the gel tube being measured so that only the light being transmitted through the polyacrylamide gel would be detected by the spectroflourometer.

First, the instrument was calibrated with a tube filled with polyacrylamide gel but no light source (LED) present. The spectral intensity at the output end of the one-foot, half-inch tube was then measured with the red LED shining into the input end of the tube. This process was repeated for the two-foot and three-foot half-inch diameter tubes with the red LED. Then, the one-foot and two-foot quarter-inch gel tubes were tested with the red LED. Next, the red LED was replaced by the white LED, and the spectral intensity at the end of each tube length was measured all five polyacrylamide gel tubes. Finally, the blue LED was inserted and its spectral intensity measured for each tube length. The results were tabulated in a form that could be manipulated by Excel so that graphs could be made illustrating the experiment.

CHAPTER 4

RESULTS

Experimental Results

Experiment One: Creation of Polyacrylamide Gel and Electric Excitation Test

Two one-inch diameter by three-eighths inch high round cylinders of polyacrylamide gel resulted from this first experiment of actually making the gel. After examining the gel, it was determined that it possessed the correct physical properties needed for this design. It was flexible, nontoxic, economical, and could be molded into any shape. Once the physical characteristics were verified, one of the small samples was subjected to a voltage across its diameter to determine if the voltage excited the atoms in the polyacrylamide gel. However, this experiment did not work properly, and the gel simply changed colors as the area around the exposed wires heated up from the increase in voltage (current). These results disproved alternative three, and extensive testing on the light transfer properties of the polyacrylamide gel began.

Figure 5: Initial Polyacrylamide Gel Samples

Experiment Two: Creation of Polyacrylamide Gel Tube and Initial Tests

One three-foot, half inch diameter tube and two four inch, half inch diameter tubes each filled with polyacrylamide gel resulted from this experiment. In one of the four-inch sections of gel tube, the gel at one end was formed with an LED inserted in the tip of the tube. Therefore, a smooth connection resulted between the LED and the gel. Light from a red, white, and blue LED were each transmitted through the three-foot section of polyacrylamide gel tube, and their approximate transmission length was observed. The light from the red LED was transmitted almost the entire distance of tube, which was approximately two and three quarter feet. The amount of light emitted from the end of the tube was also noted, for comparison with the white and blue LEDs. Furthermore, it was observed that although some of the light was transmitted through the gel, about half of the LED's light was emitted along the sides of the tube throughout its entire length. The white LED's transmission distance was less than the red LED's distance at approximately two feet. Additionally, the amount of light emitted from the end of the tube appeared to be less than for the red LED. It then became apparent that the polyacrylamide gel was acting as a filter that passed certain wavelengths (colors) of light better than others did, with red transmission being greater than white. Finally, the blue LED's light was transmitted only about one and a half feet through the gel tube before it appeared to disappear. Similar to the white LED, the blue LED's light emitted out of the end of the tube was considerably less than either the red or the white LED. The observation made with the white LED was reinforced with the blue LED's failure to transmit through entire length of the gel tube: the polyacrylamide gel was acting as a light filter that transmitted certain wavelengths of light better than others did. The same effect of leakage of light throughout the length of the tube was similarly observed for the white and blue LEDs. A picture of the three-foot section of the polyacrylamide gel light tube is shown in the following figure.

Figure 6: Three-foot Long, Half-inch Diameter Gel Tube

Each color LED was then tested with the two four inch sections of gel tube. The same effect was observed for each color LED. The tube with the matched end that allowed a smooth transmission of light from the LED to the gel seemed more intense for each color than the tube without a smooth connection. This was a result of a better impedance made between the gel and the LED that resulted in less reflections of light at unmatched end. This idea is very similar to the concept of impedance matching in transmission lines circuits and analysis. Based on the observations of light transmission through the polyacrylamide gel made in this experiment, a third experiment was then performed to determine the wavelengths of light of each of the different color LEDs.

Experiment Three: LED Frequency Spectrum Analysis

The frequency spectrum experiment yielded several results, some of which reinforced proven knowledge. For the red LED, the frequency spectrum spiked around 640 nanometers, which verified existing knowledge of the wavelength of red light. Then, the blue LED spiked around 480 nanometers, which is typical of blue light. The white LED, however, spiked around both 490 nanometers and 560 nanometers, which seems somewhat atypical since white light should contain the entire frequency spectrum of visible light. It is possible, however, that LEDs utilize a special scheme to emit white light by combining certain wavelengths around 490 and 560 nanometers. Therefore, based on the results from the Spectroflourometer, the polyacrylamide gel transmitted higher wavelengths of light more efficiently than lower wavelengths of light. This explains why the red light was transmitted farther through the gel tube since it had the highest wavelength at 640 nanometers. Furthermore, the white light's 560 nanometer component (yellow light) was transmitted, but its 490 nanometer component (blue-green light) was not transmitted as far. This explains why the white light was not as intense as the red light—half of its spectrum was not completely passed through the gel tube. Finally, the blue light's 480 nanometer component was only transmitted about one and a half feet, which was similar to the white light's 490 nanometer component. Therefore, the blue light was not visible in the last half of the tube since its only component was at 480 nanometers. Based on these observations, a fourth experiment was performed to measure the spectral intensity of the light being emitted at the end of the tube.

Experiment Four: Creation of Various Polyacrylamide Gel Tubes

A two-foot and a one-foot, half-inch diameter tube, and a two-foot and a one-foot one fourth inch diameter tube each filled with polyacrylamide gel resulted from this experiment. These tubes were developed to be used in the following experiment to measure the spectral intensity of each color LED at lengths of one foot, two feet, and three feet.

Figure 7: One-foot & Two-foot Long, Half-inch & Quarter-inch Diameter Gel Tubes

Experiment Five: End of Tube Spectral Intensity Test One

After several tubes of different lengths and diameters were made, the spectral intensity of the light being emitted out of the end of each tube was measured for each color LED. The spectral intensity for the white LED at the end of each of the half-inch gel tubes was measured and recorded in units of counts per second (cps) versus wavelength in units of nanometers (nm). This data was tabulated and downloaded to Excel where graphs were developed to display the measurements. The following graph illustrates the white LED's transmission characteristics for each length of the polyacrylamide gel tubes.

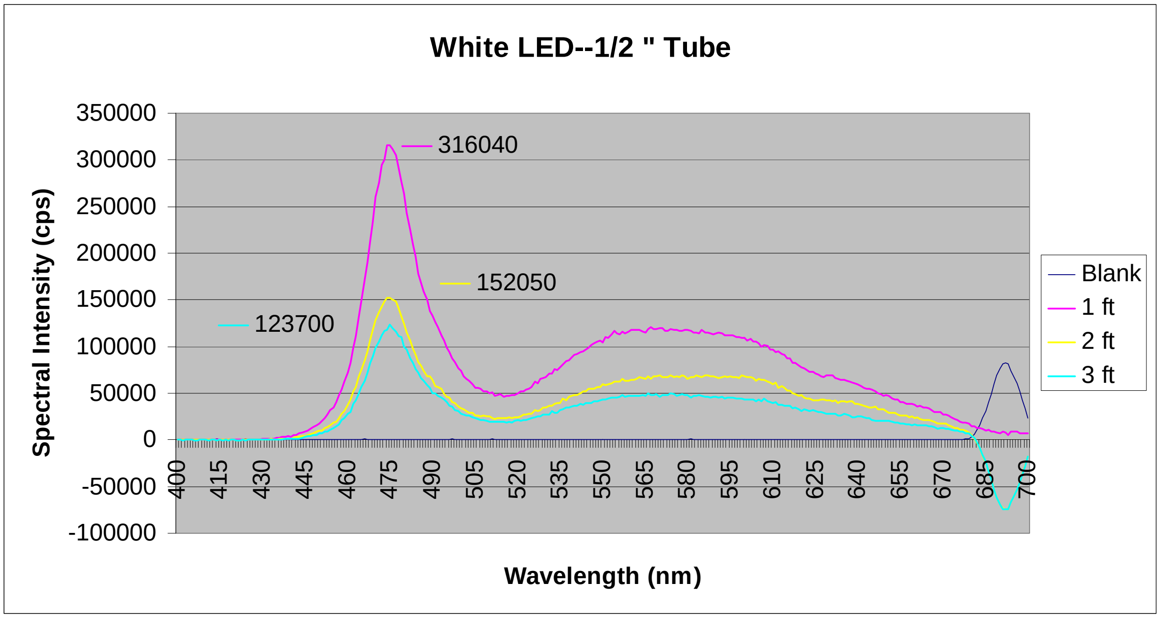

Figure 8: Output Spectral Intensity of Half-inch Diameter Gel Tube with White LED

It is evident that the spectral intensity at the output of each tube length decreases as the length of the gel tube increases. However, the peak wavelength for the white LED appeared at 475 nanometers, which is characteristic of blue light, not white light. Therefore, it is possible that ambient light interfered with the spectroflourometer.

Next, the spectral intensity for the red LED at the end of each of the half-inch and quarter-inch gel tubes was measured and recorded in the same manner as the white LED. The following two graphs illustrate the red LED's transmission characteristics for each section of the polyacrylamide gel tubes.

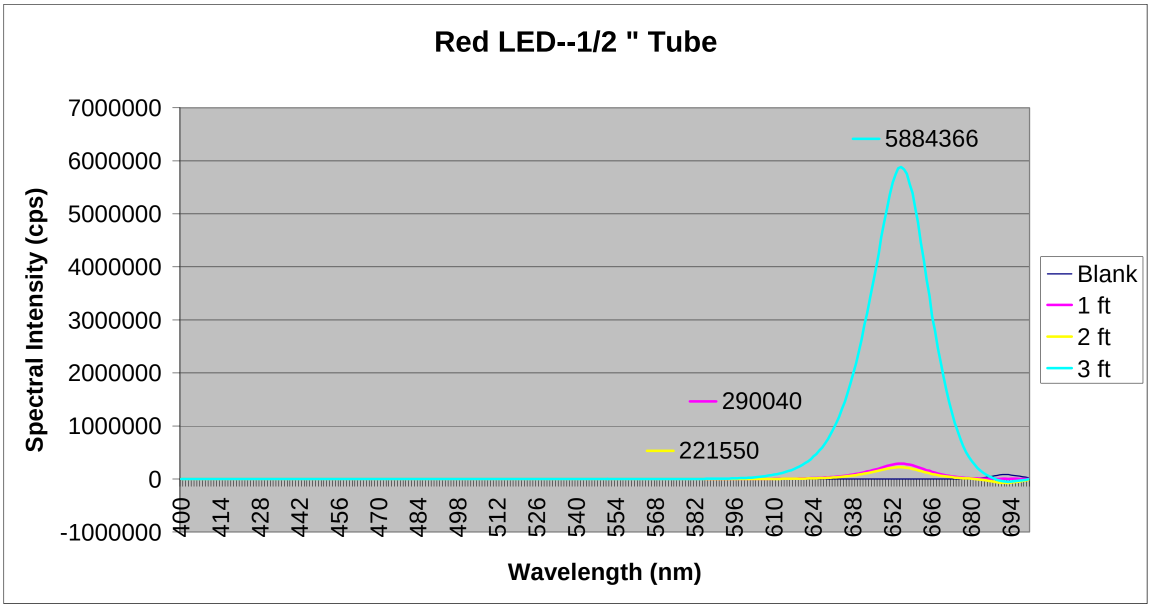

Figure 9: Output Spectral Intensity of Half-inch Diameter Gel Tube with Red LED

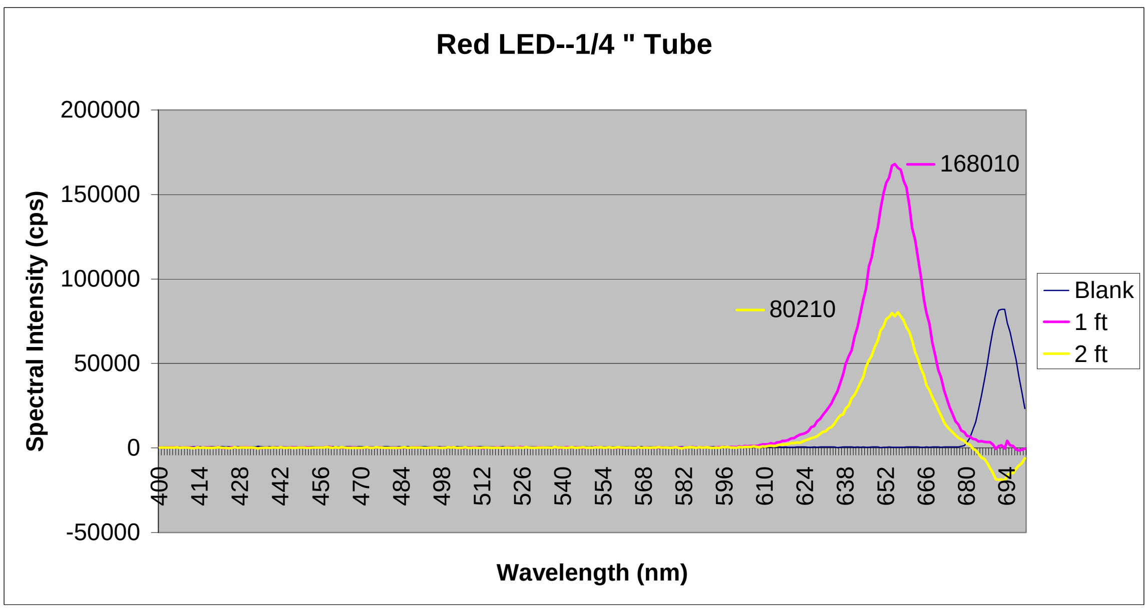

Figure 10: Output Spectral Intensity of Quarter-inch Diameter Gel Tube with Red LED

It is obvious that the results in Figure 10 contradict the theory that the spectral intensity at the output of each tube length decreases as the length of the gel tube increases since the spectral intensity of the three-foot gel tube is far greater than the one or two-foot gel tubes. This fact reinforces the possibility that ambient light interfered with the spectroflourometer. It is clear, however, that the larger diameter gel tube transmits more of the red LED's light than the smaller diameter tube. The peak for the red LED appeared at a wavelength of 655 nanometers, which is fairly close to the 640 nanometer prediction made earlier.

Finally, the spectral intensity for the blue LED at the end of each of the half-inch gel tubes was measured and recorded in the same manner as the red and white LEDs. The following graph illustrates the blue LED's transmission characteristics for each section of the polyacrylamide gel tubes.

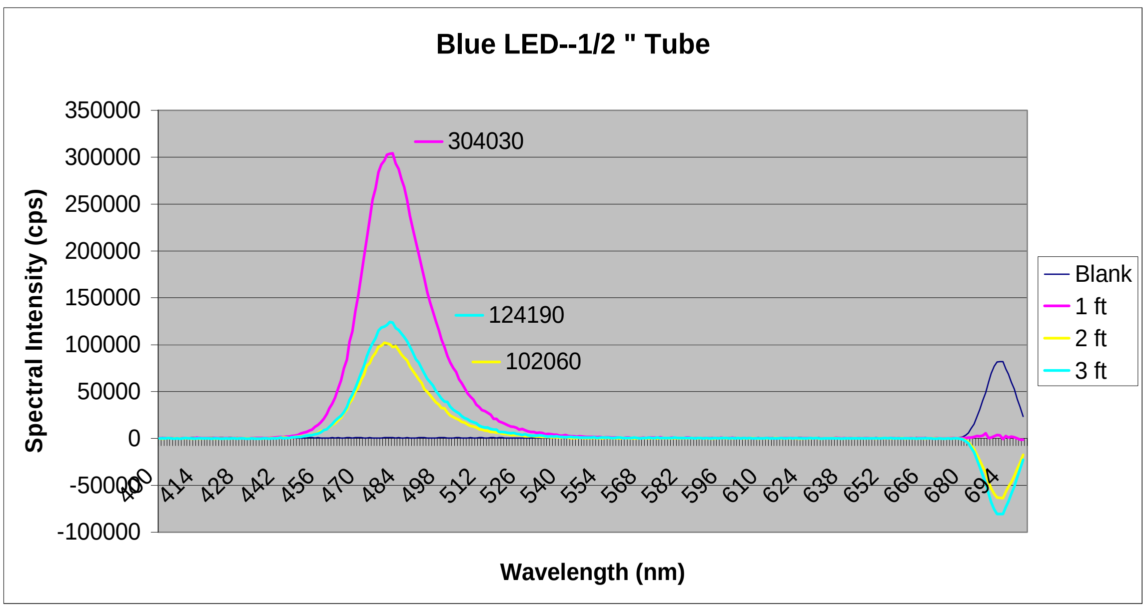

Figure 11: Output Spectral Intensity of Half-inch Diameter Gel Tube with Blue LED

For the blue LED, the spectral intensity at the output of the one-foot gel tube is higher than the two and three-foot tubes, as was expected. However, the three-foot tube's spectral intensity is slightly higher than the one-foot tube's. This anomaly further solidifies the possibility that ambient light interfered with the experiment. The peak wavelength for the blue LED appeared at 481 nanometers, which is very close to the 480 nanometer prediction made earlier.

Based on the analysis of the data recorded for this experiment, it is concluded that some type of ambient light interfered with the measurement device. Therefore, the results presented here do not represent the actual behavior of the polyacrylamide gel tube. Furthermore, the same experiment was performed again with careful attention given to controlling the conditions of the experiment, particularly by eliminating the possibility for ambient light to enter the measurement device. The results for this second experiment are given in the following section.

Experiment Six: End of Tube Spectral Intensity Test Two

Once the ambient light contamination problem was solved, the polyacrylamide gel light tube transmitted the light as predicted. The spectral intensity for the red LED at the end of each of the half-inch and quarter-inch gel tubes was measured and recorded in units of counts per second (cps) versus wavelength in units of nanometers (nm). This data was tabulated and downloaded to Excel where graphs were developed to display the measurements. The following two graphs illustrate the red LED's transmission characteristics for each section of the polyacrylamide gel tubes.

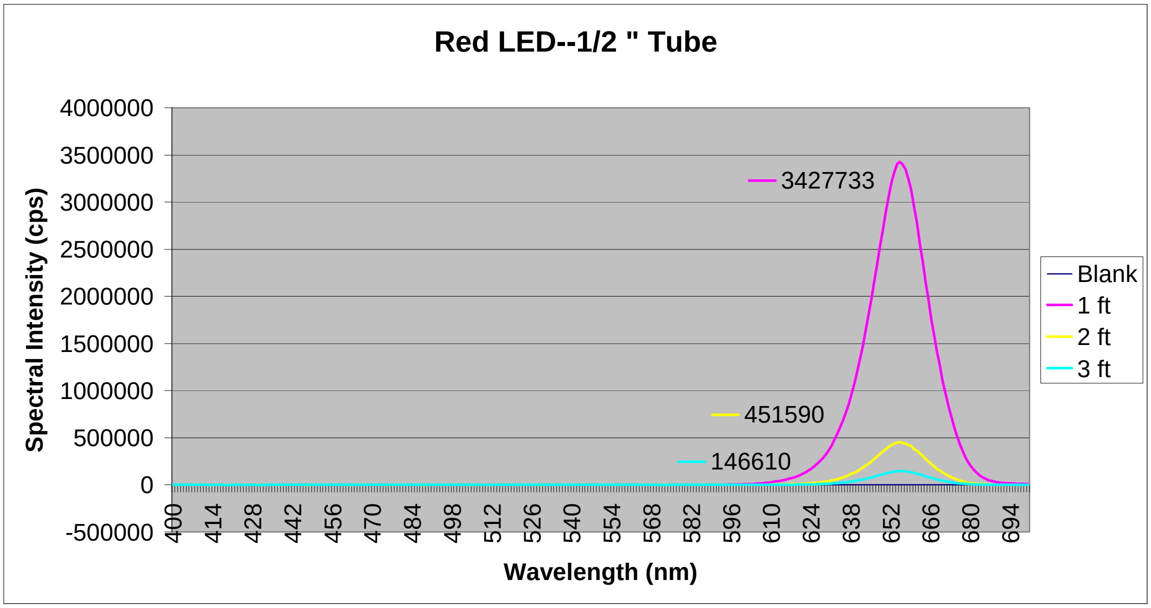

Figure 12: Output Spectral Intensity of Half-inch Diameter Gel Tube with Red LED

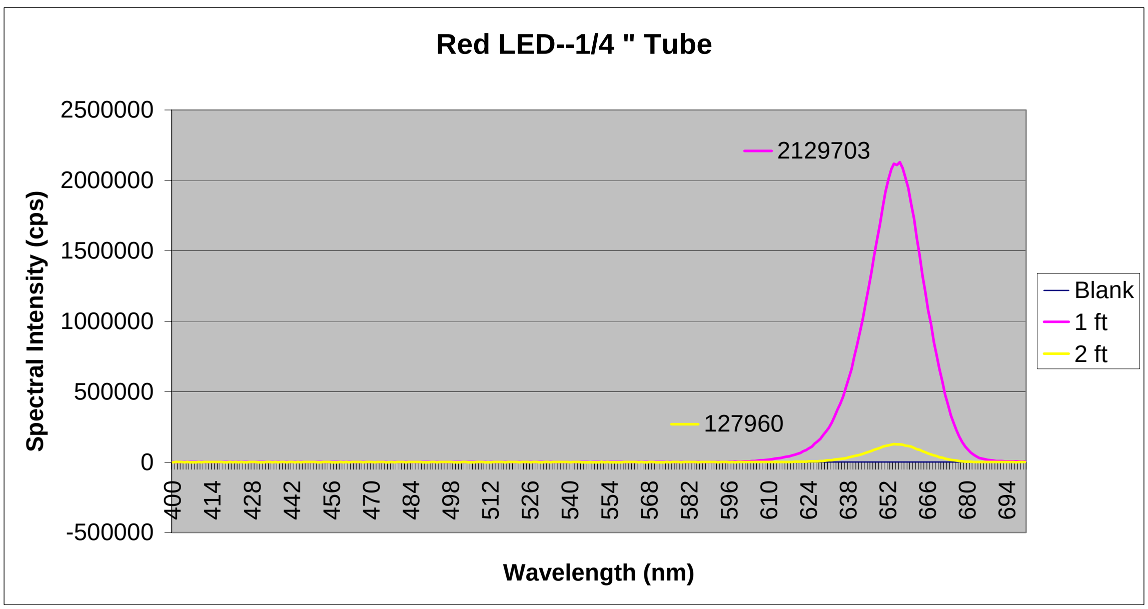

Figure 13: Output Spectral Intensity of Quarter-inch Diameter Gel Tube with Red LED

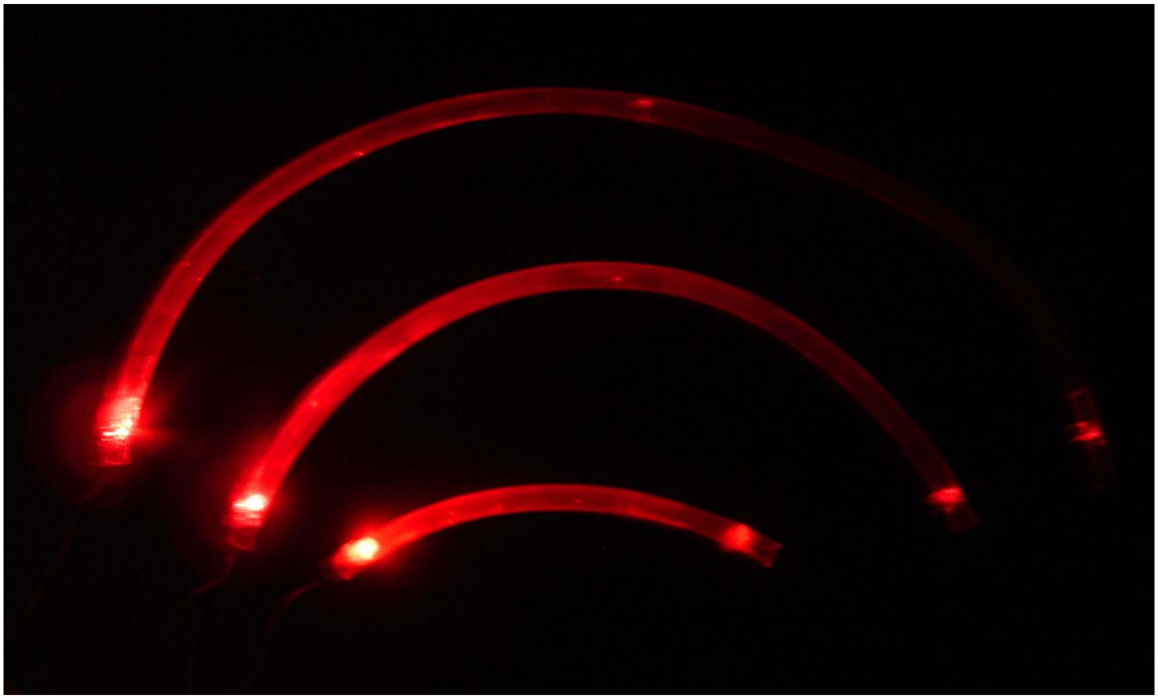

Figure 14: Picture of Red LED Gel Tube Transmission along Curved Path

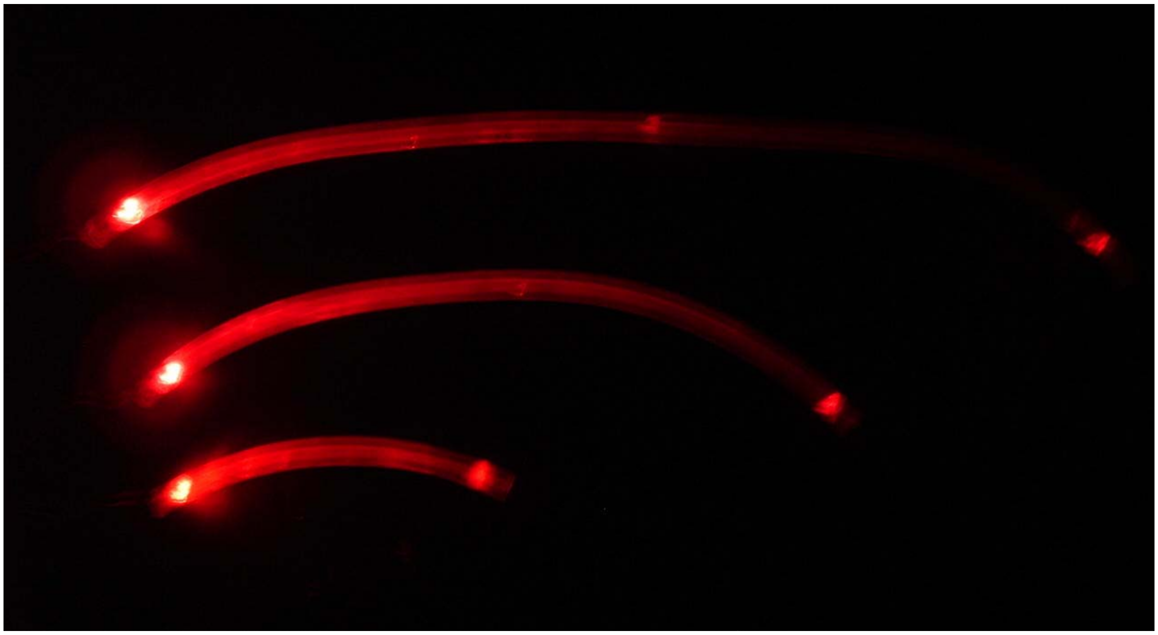

Figure 15: Picture of Red LED Gel Tube Transmission along Straight Path

Figure 16: Picture of Output Spectral Intensity of Red LED for
One-, Two-, and Three-foot Gel Tubes

It is evident that the spectral intensity at the output of each tube length decreases as the length of the gel tube increases. Furthermore, the larger diameter gel tube transmits more of the red LED’s light than the smaller diameter tube. The peak wavelength for the red LED appeared at 655 nanometers, which is very close to the 640 nanometer prediction made earlier. The photographs of the gel tubes reinforce the measured data obtained from the spectroflourometer.

Next, the spectral intensity for the white LED at the end of each of the half-inch and quarter-inch gel tubes was measured and recorded in the same manner as the red LED. The following two graphs illustrate the white LED’s transmission characteristics for each section of the polyacrylamide gel tubes.

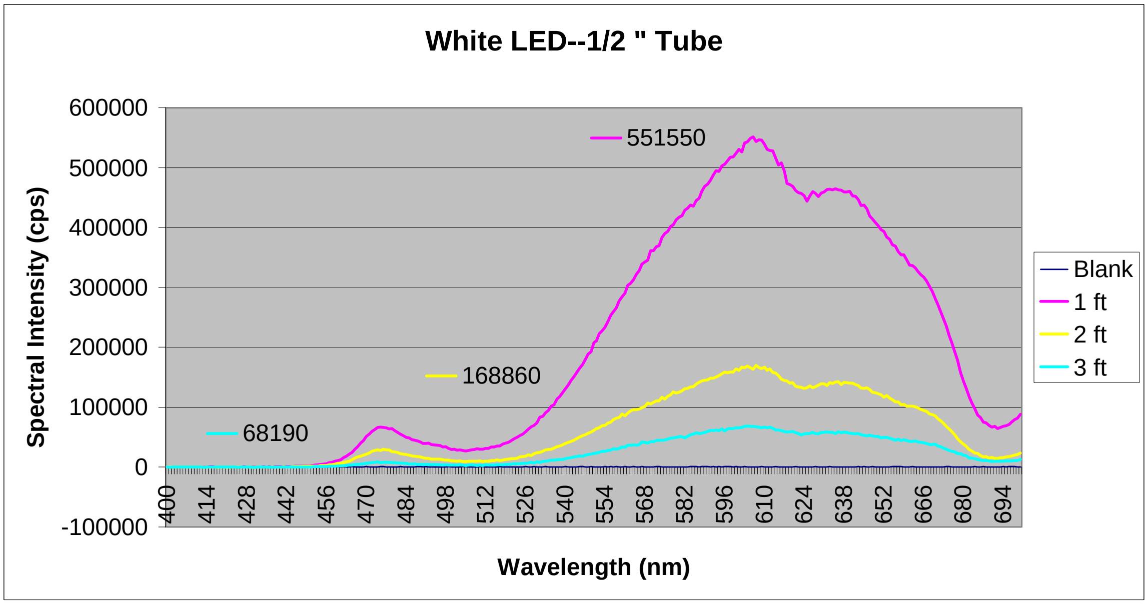

Figure 17: Output Spectral Intensity of Half-inch Diameter Gel Tube with White LED

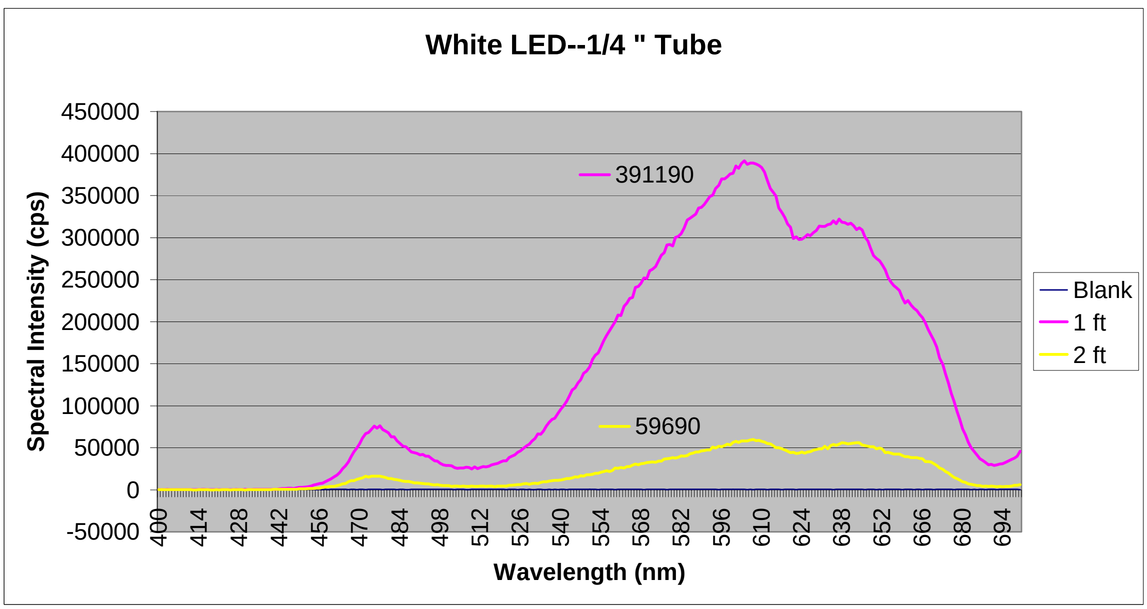

Figure 18: Output Spectral Intensity of Quarter-inch Diameter Gel Tube for White LED

Figure 19: Picture of White LED Gel Tube Transmission along Curved Path

Figure 20: Picture of White LED Gel Tube Transmission along Straight Path

Figure 21: Picture of Output Spectral Intensity of White LED for
One-, Two-, and Three-foot Gel Tubes

Again, it is evident that the spectral intensity at the output of each tube length decreases as the length of the gel tube increases. Furthermore, the larger diameter gel tube transmits more of the white LED's light than the smaller diameter tube. The two peaks for the white LED appeared at wavelengths of 475 and 606 nanometers, which is fairly close to the 490 and 560 nanometer predictions made earlier. The peak at 475 nanometers is considerably smaller than the one at 606 nanometers, which confirms our earlier observations that the polyacrylamide gel transmits higher wavelengths of light more efficiently than lower wavelengths. Additionally, the light seen at the end of the gel tube for the white LED appeared to have a yellow tint, while the light emitted directly from the white LED appeared white. The reasoning behind this observation is explained by the polyacrylamide gel passing the higher wavelength yellow light and filtering out the lower wavelength blue light that was seen in the original spectrum analysis of the white LED in experiment three. The photographs of the gel tubes reinforce the measured data obtained from the spectroflourometer.

Finally, the spectral intensity for the blue LED at the end of each of the half-inch and quarter-inch gel tubes was measured and recorded in the same manner as the red and white LEDs. The following two graphs illustrate the blue LED's transmission characteristics for each section of the polyacrylamide gel tubes.

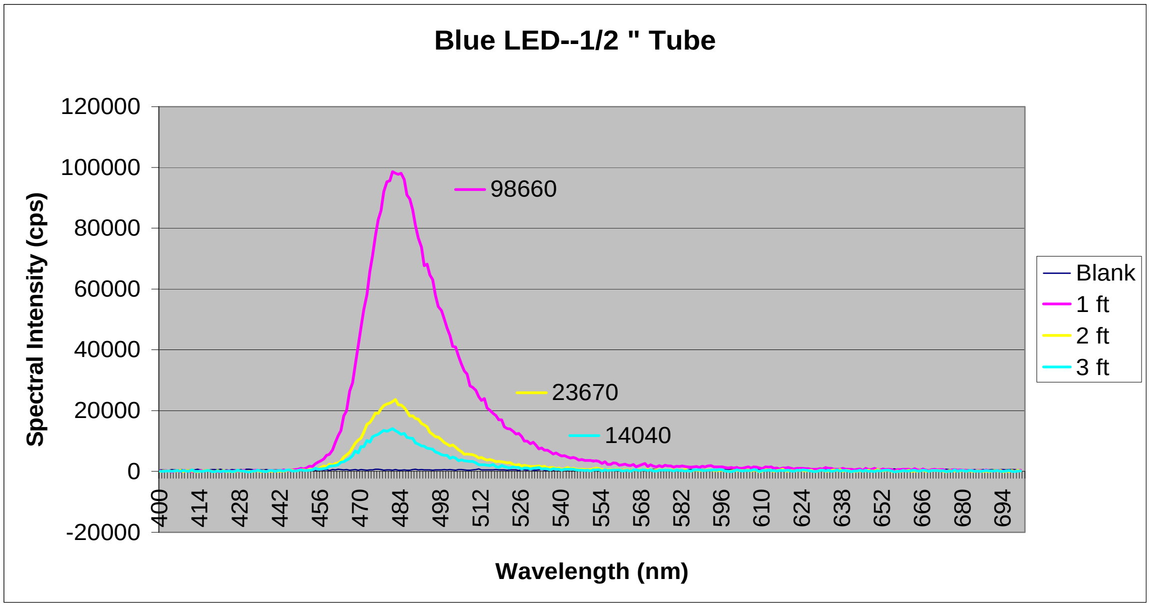

Figure 22: Output Spectral Intensity of Half-inch Diameter Gel Tube with Blue LED

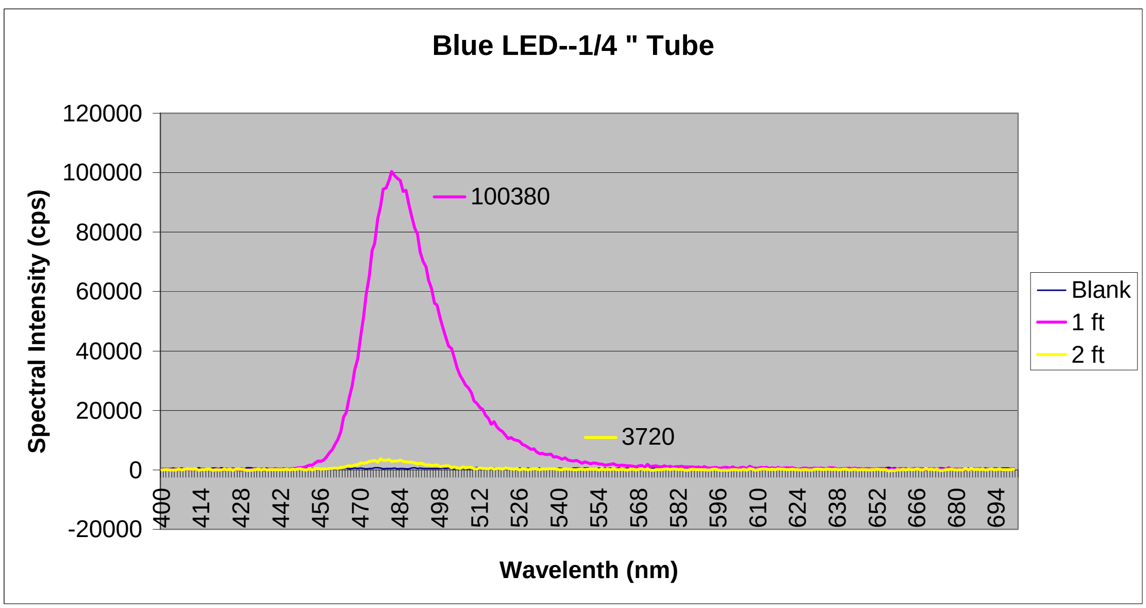

Figure 23: Output Spectral Intensity of Quarter-inch Diameter Gel Tube with Blue LED

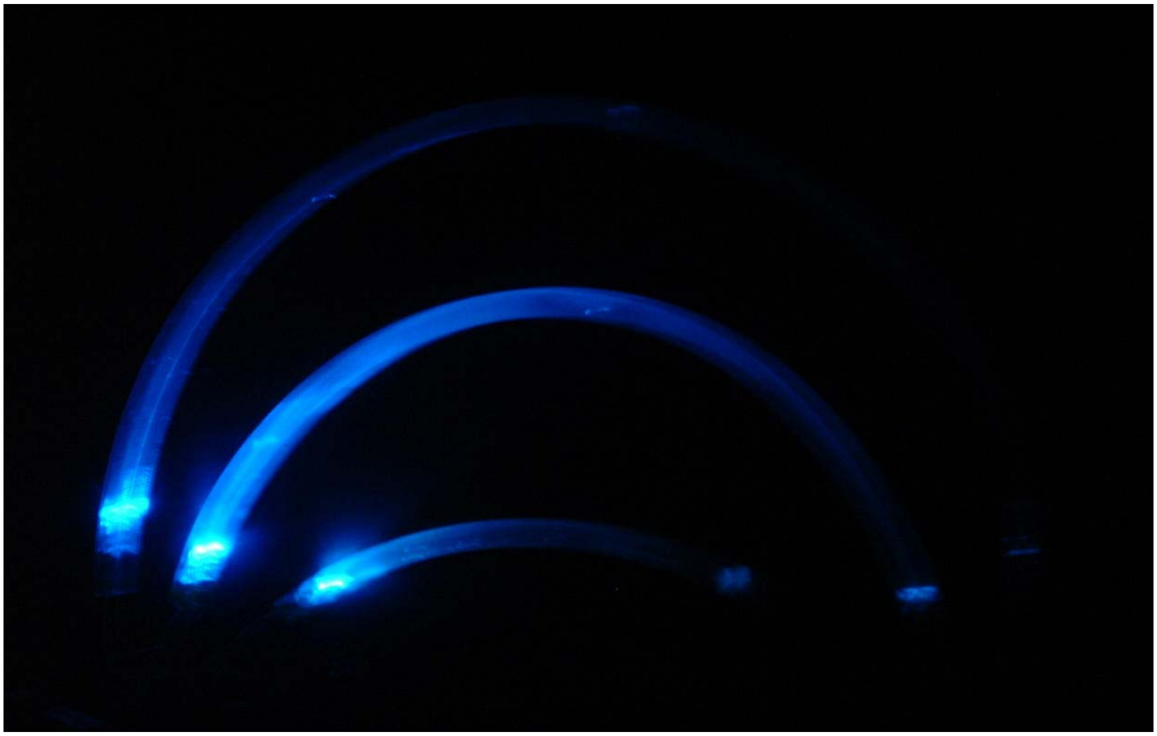

Figure 24: Picture of Blue LED Gel Tube Transmission along Curved Path

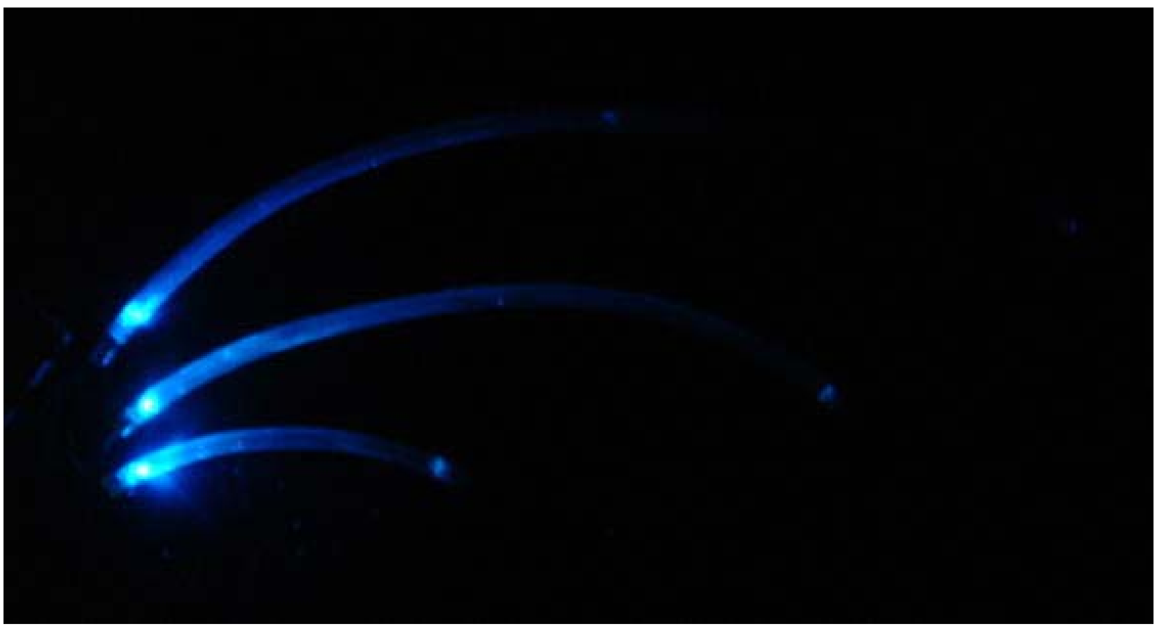

Figure 25: Picture of Blue LED Gel Tube Transmission along Straight Path

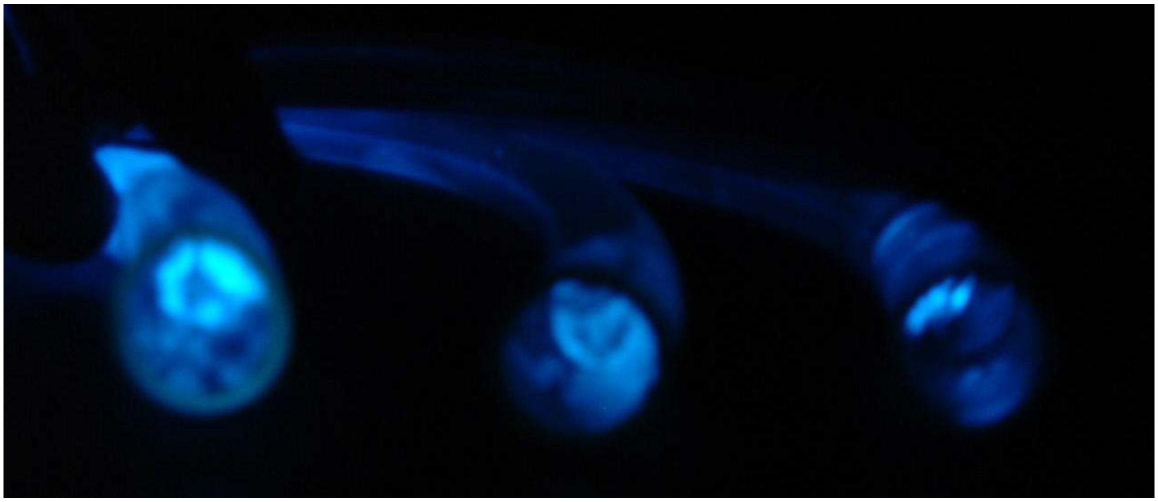

Figure 26: Picture of Output Spectral Intensity of Blue LED for
One-, Two-, and Three-foot Gel Tubes

Again, it is evident that the spectral intensity at the output of each tube length decreases as the length of the gel tube increases. The one-foot half-inch gel tube with the blue LED transmits slightly less than the one-foot quarter-inch tube, unlike the red and white LEDs. However, for the two-foot tubes, the larger diameter gel tube transmits more of the blue LED's light than the smaller diameter tube, as was the case with the red and white LEDs. The peak wavelength for the blue LED appeared at 481 nanometers, which is very close to the 480 nanometer prediction made earlier. The photographs of the gel tubes reinforce the measured data obtained from the spectroflourometer.

The following graphs compare the spectral intensities of the red, white, and blue LEDs together on the same graph for a certain length half-inch diameter tube. The first graph illustrates the one-foot gel tube results, the second graph illustrates the two-foot gel tube results, and the third graph illustrates the three-foot gel tube results.

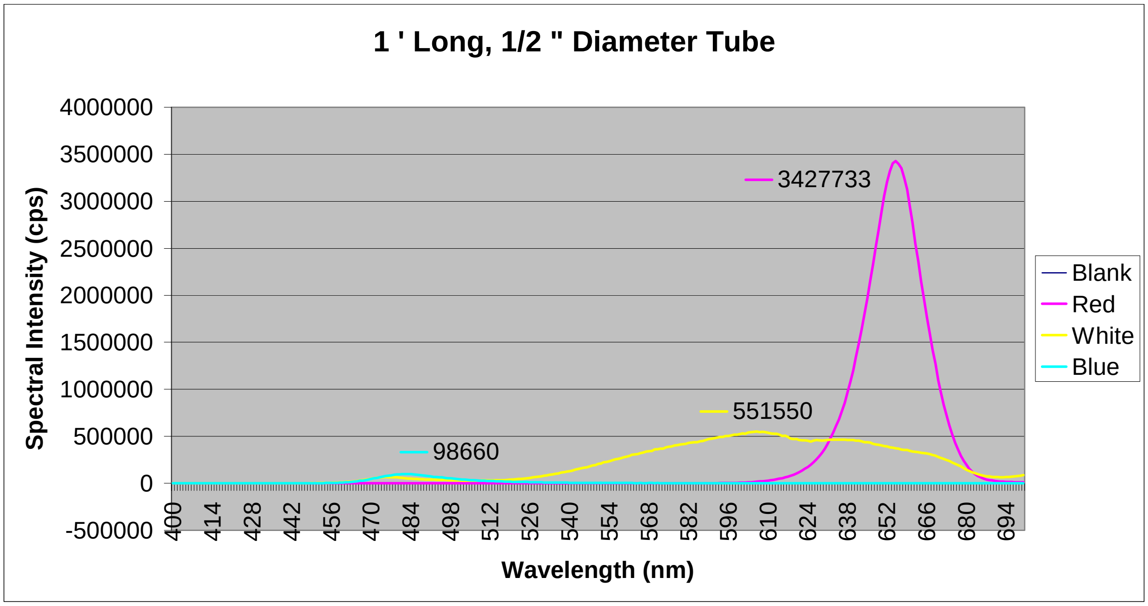

Figure 27: Comparison of Output Spectral Intensity for One-foot Gel Tube

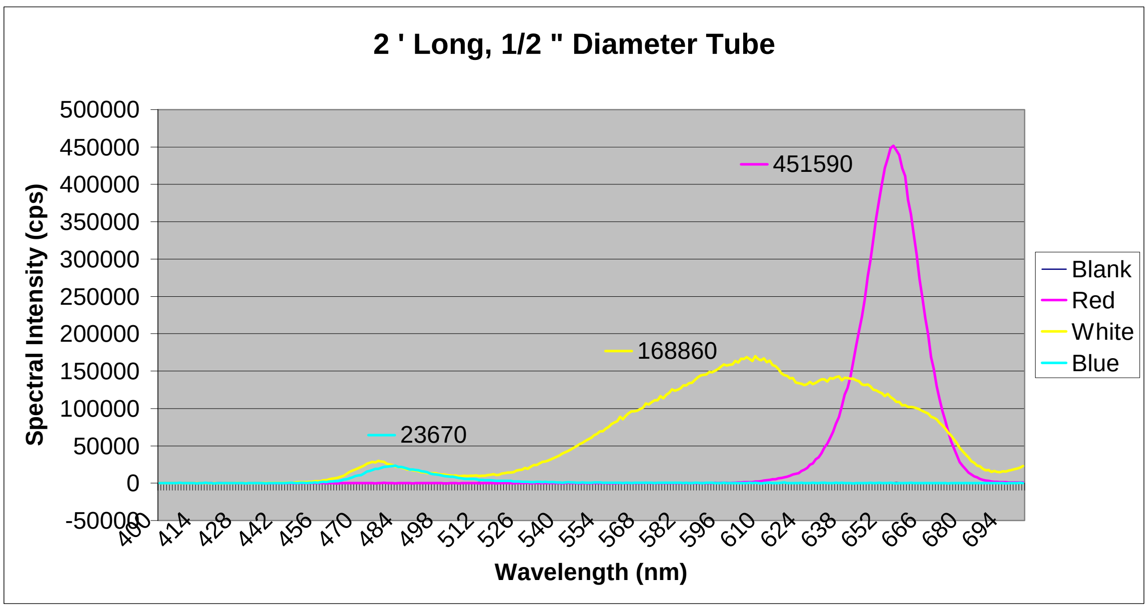

Figure 28: Comparison of Output Spectral Intensity for Two-foot Gel Tube

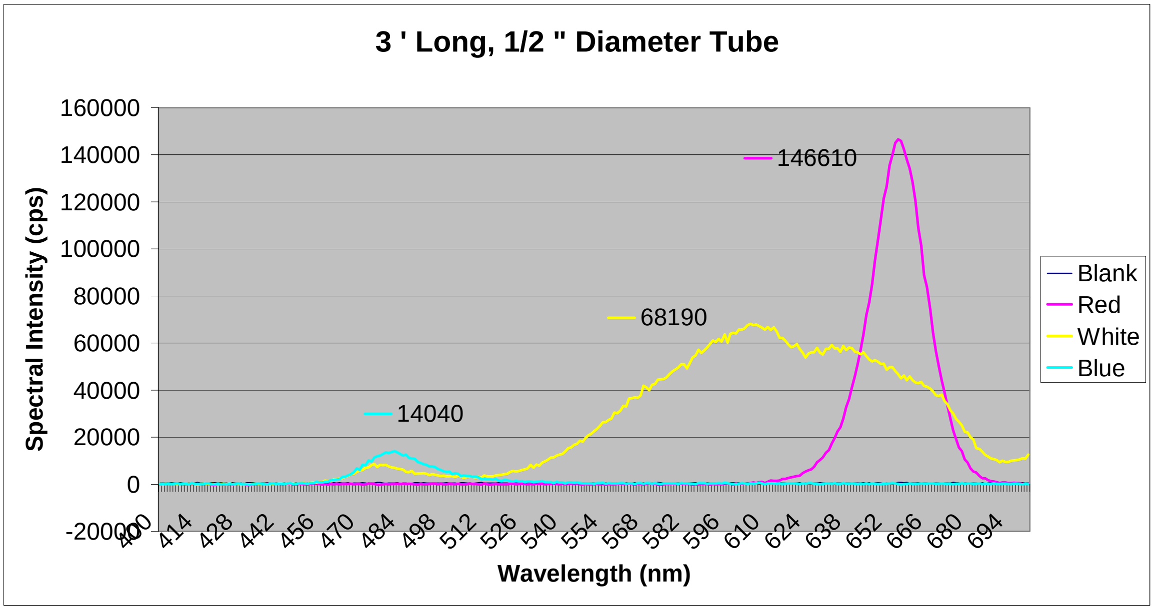

Figure 29: Comparison of Output Spectral Intensity for Three-foot Gel Tube

It is very clear from each of the above graphs that the polyacrylamide gel tubes pass the wavelength of red light much better than the white or blue light. Furthermore, the gel passes the wavelength of white light better than that of blue light. For the one-foot gel tube, the red LED's spectral intensity is 6.21 times greater than the white LED's, while it is 34.74 times greater than the blue LED's. For the two-foot gel tube, the red LED's spectral intensity decreases to only 2.67 times greater than the white LED's, while it decreases to only 19.08 times greater than the blue LED's. Finally, for the three-foot gel tube, the red LED's spectral intensity decreases to 2.15 time greater than the white LED's, while it decreases to 10.44 times greater than the blue LED's. Therefore, it is clear that as the length of the tube increases, the polyacrylamide gel does not carry as much of the light through the tube. The main explanation for less light being emitted from the end of the tube for longer lengths is the leakage of light from the sides of the tube. This effect could be lessened by shielding the tube along its length to create a more ideal “fiber optic” light tube.

CHAPTER 5

DISCUSSION

Throughout the experimental process, several relevant findings were discovered. First, bounded by my own lack of chemical knowledge and the equipment available, I was not able to cause polyacrylamide gel to emit light without an external light source. According to Dr. Dale Moore, however, it is possible that adding polymer electrolytes to the polyacrylamide gel would cause it to have conductive properties that could make the gel emit light if excited by an electrical current or voltage. On the other hand, I did discover that the polyacrylamide gel does transmit light from one place to another through a gel tube when an LED is used as an external light source. The downside to this discovery is that the amount of light transmitted decreases as the length of the tube increases. This is mainly caused by a large amount of the LED's light leaking out through the sides of the tube. One solution to this problem is to shield the tube until the desired transmission length has been reached. Then, the light should be almost completely transmitted through the shielded length of the gel tube until the shield ends, at which point the light will be emitted as before. Moreover, a leaky shield, one that has holes at certain points along the tubes length, may be desirable in some situations. Another noticeable discovery was that the light transmission was improved by matching the impedance of the LED with the gel. This matching was accomplished by making a smooth connection between the gel and the LED by inserting the LED into the gel as it was formed. Finally, the polyacrylamide gel transmitted higher wavelengths of light (red light) better than it did lower wavelengths (blue light).

Based on the observations made during the experiments and my research, the polyacrylamide gel light tube appears to be similar to fiber optic cables in their transmission of a signal (light) from one place to another via reflections inside a tube [4,5,6]. Therefore, this new device has numerous applications in the automotive and military industries. The LED gel light could be used in vehicles or planes to illuminate areas where normal ambient light does not reach. Furthermore, in the consumer goods industry, the gel light could be placed in the bottom of pocketbooks to make it easier for a woman to find what she is looking for since it is difficult to see inside most pocketbooks.

There are several future experiments that would further the development of this new technology. The first would involve determining how a shield would affect the light transmission through the polyacrylamide gel tube and determining the effect of applying a leaky shield. Secondly, the determination of the index of refraction of the polyacrylamide gel and the tube would aid in controlling the reflections light as it passed through the tube. Finally, experimenting with different types of tubes may yield better results than the ones used in these experiments.

CHAPTER 6

SUMMARY

This project began with initial study in the areas of gels and fiber optics. Then, after brainstorming ideas of how to design a light source using gels, several experiments were performed that involved testing the light transfer properties of polyacrylamide gels with different colors of LEDs for different length and diameter gel tubes. The experimental process consisted of first developing a polyacrylamide gel tube. Then, the visual properties of the LED’s light transmittance were observed and analyzed. More experiments were then performed to obtain a quantitative measure of the amount of light that was being transmitted for each color of LED. This experiment involved measuring the output spectral intensity at one foot, two feet, and three feet lengths. It was determined that the polyacrylamide gel transmitted higher wavelengths of light (red) better than lower wavelengths of light (blue). Furthermore, the output spectral intensity decreased as the length of the tube increased. The tube’s diameter also affected the transmission of the light: larger diameter tubes transmitted light more efficiently than smaller diameter tubes. Based on these experiments, several ideas were developed for how the polyacrylamide gel light tube could be used in a practical setting. Of these ideas, the most notable were for the automotive, military, and consumer industries.

CHAPTER 7

CONCLUSIONS

The polyacrylamide gel light tube illuminated by an LED has numerous future applications. Normal ambient light does not reach an endless number of corners or areas in the world today. Many of these areas can be seen by just looking around right now. By designing a flexible, lightweight, long-lasting, and non-toxic polyacrylamide LED gel light, I have made it possible for people to see in areas where it was difficult to see because the amount of light was minimal. However, there is still much research and experimentation to be completed before an actual model could be implemented for practical use. Topics such as shielding, altering the index of refraction, changing the tube material, and inserting polymer electrolytes should all be discussed and analyzed before a practical model is finalized. Additionally, the best method interfacing the LED and electrical circuitry with the gel in order to minimize size and weight while completely sealing the gel from air should be determined. Therefore, this project is still in the experimental phase and should continue through to a prototype construction and testing phase if and when time permits.

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