Project #3

Measurement of Tissue Optical Attenuation Coefficient

BE 5344

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Introduction

As human society advances, the more opportunities to discover and explain daily life phenomena. Therefore, the younger generation will be able to access a better and deeper understanding of how the surrounding factors could affect the outcome of the experiment. Since light is one of the essential phenomena that happen every day thus, the measurement of how "quickly incident light is attenuated when passing through a medium"- the optical attenuation coefficients (AC), allow the searchers a closer view on how light scattering while passing through different tissues. (1)

Every signal will have a reduction in its strength the further it travels, therefore, the collection of data of scattering and absorption of it will assist on detection of the attenuation of the said medium while affected by the source. When the light source encounters the solution that contains water and milk, it strikes the diode which leads to the production of electron-hole. These electrons go toward the cathode (+) and the hole will be attracted by the anodes (-) as the opposite force attracts each other. (2) These attractions will create a photocurrent which allows the detection fiber to pick up and brighten bulb.

In this experiment, the circuit with the source and detector fiber will be set up to detect the attenuation of the light when it passes through different mediums of water and milk. The circuit will allow the students to calibrate and learn how mediums will influence light detection. Using the oscilloscope, we will observe how the system response, record the data for further filtering and analysis.

Methods and Materials

For the "Measurement of tissue optical attenuation coefficient" we used the following components:

- LED (Light Emitting Diode) circuit
- Photodiode circuit
- Oscilloscope
- Waveform generating machine
- Optical fiber bundle x2
- Translation and rotation stages
- Optical breadboard
- Beaker with water
- Beaker with water and milk
- Ruler
- Screwdriver

The LED circuit consisted of a 150Ω resistor and power supply in the form of square waveforms. The square waveforms had a frequency of 1 kHz, a peak-to-peak voltage of 4 V and a DC offset of 2 V. The blue LED was used and the diagram is shown below:

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Commented [MD2R1]: I think we used 150 ohm?

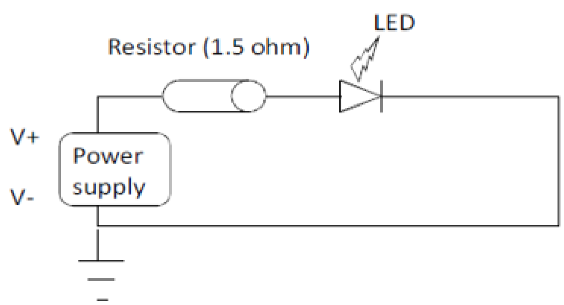


Figure 1. The diagram of the LED circuit.

The photodiode circuit consisted of 1KΩ resistor, photodiode, 0.1 μF capacitor, 1MΩ resistor and voltage supply.

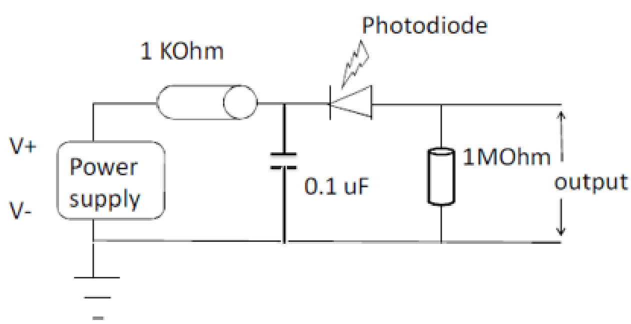


Figure 2. The diagram of the photodiode circuit.

The setup included putting two optical breadboards together. One optical fiber bundle was taped together with the blue LED while the second optical fiber bundle was taped together with the photodiode. The other ends of both optical fiber bundles were submerged into the beaker with water or the beaker with a mix of water and milk. Oscilloscope was used to visualize the signal and obtain the voltage peak to peak values. The waveform generator was used to power the LED circuit at specified frequency, DC offset, and voltage peak to peak. The setup can be observed in the below figure:

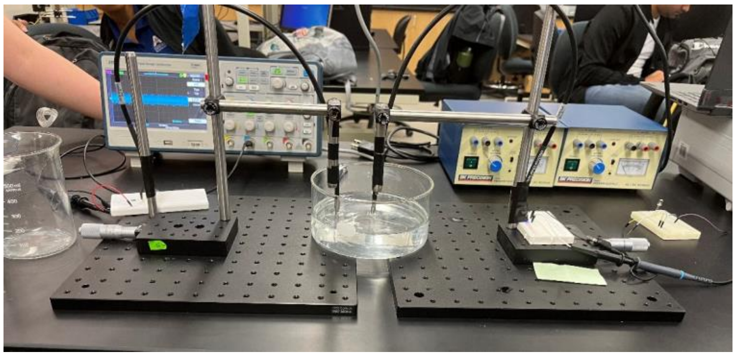


Figure 3. The setup of the project.

To obtain data, various distances between optical fiber bundles were used to obtain peak-to-peak voltage values. Also, various concentrations of mixture of water and milk were used to collect data of concentration caused voltage changes.

The following concentrations were utilized:

- 500 ml water + 0 ml milk
- 500 ml water + 100 ml milk

The distances between optical fiber bundles that were tested started with 0.5 cm and the distance was increased by increments of 0.5 cm until 5 cm final distance was achieved.

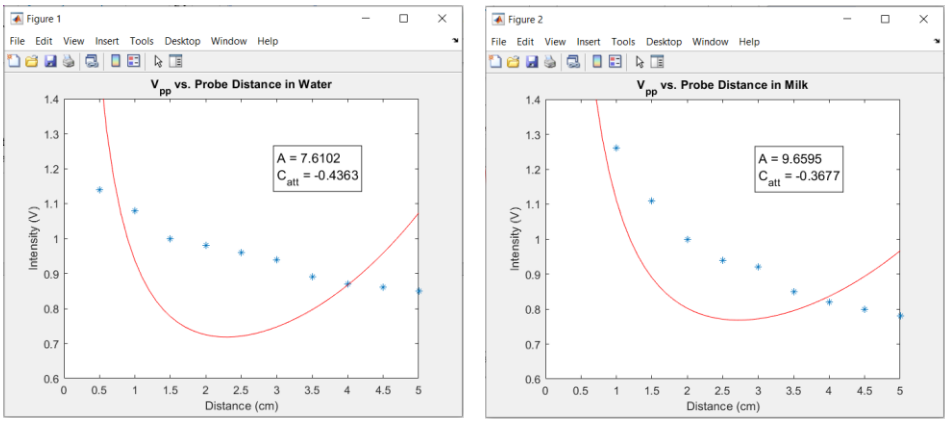
Results and Discussion

The peak-to-peak voltage values recorded from the oscilloscope were first plotted as data points in MATLAB for both experiments using water and a mix of water and milk (Figures 4a and 4b). A non-linear curve fitting model was then generated in MATLAB using the code found in Appendix A to determine the optical attenuation coefficient for each medium based on the data. The following formula for optical attenuation was used as the function for the model, where V_{pp} is light intensity (represented as peak-to-peak voltage measured in volts), A is a constant, r_{sd} is the distance between the optical fiber bundles (measured in cm), and C_{att} is the attenuation coefficient (cm^{-1}) .

Commented [TN3]: Not sure if this is the correct unit

$$V_{pp} = A\frac{e^{-C_{att}\,r_{sd}}}{4\pi r_{sd}} \qquad (1)$$

The equation was fitted to the acquired data using the MATLAB function ‘fitnlm,’ which produced estimates for the parameter values A and C_{att}, as well as an R^2 value to quantify how well the model fit the data. The resulting curves were also plotted as lines, as shown in Figures 4a and 4b, to help visualize how well the model fits the experimental data.



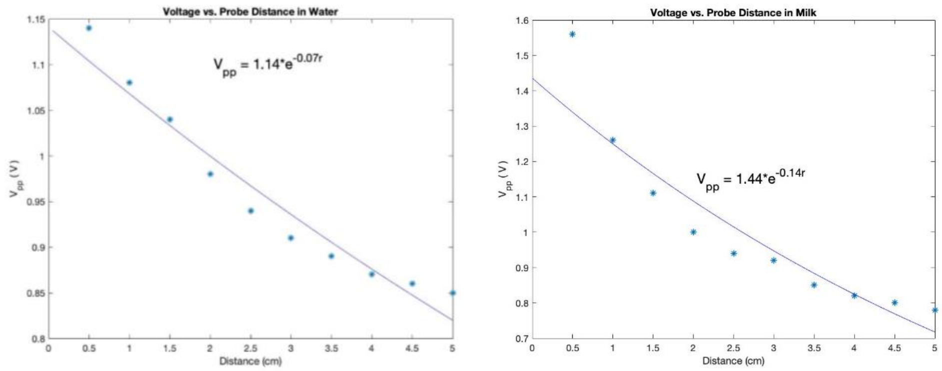
(a) (b)

Figure 4. Experimental data and results from non-linear curve fitting model plotted to show relationship between measured light intensity and distance between optical fiber bundles in (a) water and (b) water mixed with milk.

The optical attenuation coefficient of water as estimated by the model was -0.4363 cm^{-1}, while the milk and water mix had an estimated coefficient of -0.3677 cm^{-1}. The R^2 values for the two experiments were -4.13 and 0.469, respectively.

As indicated by the plots and low R^2 values, the non-linear curve fitting model using the optical attenuation function did not appear to be a good fit for our data. Hence, we tried to achieve a better fit using a simple exponential regression model generated by the MATLAB code in Appendix B. The model follows the general exponential function shown below. The MATLAB function ‘polyfit’ was used to generate the exponential fit model and produced estimates for B and C_{att}. The results from the model were then fitted to the data and plotted as shown in Figures 5a and 5b.

$$V_{pp} = Be^{C_{att}\ r_{sd}} \qquad (2)$$



(a) (b)

Figure 5. Experimental data and results from exponential curve fitting model plotted to show relationship between measured light intensity and distance between optical fiber bundles in (a) water and (b) water mixed with milk.

Based on the plots, the exponential regression model appeared to be a much better fit for our data. This was corroborated by the calculated R^2 values, which were higher and closer to 1, indicating a stronger correlation. The first experiment with water as the medium had an R^2 value of 0.9448, while the second experiment using a mix of water and milk had an R^2 value of 0.9093. The optical attenuation coefficients estimated by the model were 0.07 cm^{-1} for water and 0.14 cm^{-1} for water mixed with milk.

Despite the exponential model providing a better fit for our data, the results it generated may not be accurate estimates of the function parameters. When comparing the functions for the two fit models used, we assumed that the parameter B in Equation 2 would be an equivalent encompassing both the constant A and the term $1/4\pi r_{sd}$ from Equation 1. However, that assumption would mean that B would become a variable rather than a constant parameter since it would change with the variable r_{sd}.

We also tried various other linear, nonlinear, and exponential regression models but could not get a better fit for our data. Due to time limitations, our sample size was small; hence, it prevents us from obtaining the best-fit equation to calculate the attenuation coefficients. In addition, the purity of water may change the result, thus, it may affect the calculation of the final optical attenuation coefficient of water and milk. Moreover, noise and calibration errors inherent in the digital oscilloscope could also influence our final result**.**

Conclusion

In conclusion, we see through the results that the light intensity decreased as distance between the optical fibers increased in both water and water mixed with milk as seen in figures

4a and 4b. A larger decrease in light intensity was seen in the water mixed with milk supported by its higher attenuation coefficient of -0.3677 compared to that of the water which was -0.4363. Furthermore, despite the optical attenuation function not being a good fit for our data, this conclusion is still supported by the simple exponential regression model used to try to achieve a better fit as seen in figures 5a and 5b where the optical attenuation coefficients for the water and water with milk medium were 0.07 and 0.14 respectively. This shows that distance and concentration of a medium influence light intensity. The larger the distance and concentration, the faster and larger the attenuation of light.

References

Canfield, L. R. (2007, May 29). *Photodiode detectors*. Vacuum Ultraviolet Spectroscopy. Retrieved April 27, 2022, from https://www.sciencedirect.com/science/article/pii/B9780126175608500281?via%3Dihub#section-cited-by

Chang, S., & Bowden, A. K. (2019). Review of methods and applications of attenuation coefficient measurements with optical coherence tomography. Journal of biomedical optics, 24(9), 1–17. https://doi.org/10.1117/1.JBO.24.9.090901

Appendix A

Non-linear Regression

```
%% Water
r = [0.5,1,1.5,2,2.5,3,3.5,4,4.5,5]'; %distance b/w probes (cm)
vw = [1.14,1.08,1,0.98,0.96,0.94,0.89,0.87,0.86,0.85]'; %light intensity in
terms of voltage (V)

%Plot raw data
figure
plot(r,vw,'*');
title('V_p_p vs. Probe Distance in Water')
xlabel('Distance (cm)')
ylabel('Intensity (V)')

%Non-linear curve fitting model
%fitting attenuation function to data
modelfun=@(p,r) p(1)*((exp(-p(2)*r))./(4*pi*r)); %define model function for
fitting, w/ parameters p and variable r
beta0 = [1 1]; %guess values for initial parameters p
ft=fitnlm(r,vw,modelfun,beta0) %fits model to the data --> generates
estimated parameter values
r2 = [0:0.1:5]; %theoretical r values
yfit = feval(ft,r2); %input theoretical r values into model to get resulting
fitted curve
p = ft.Coefficients.Estimate; %stores estimated A & C values generated by
curve fit in a vector
hold on
plot(r2,yfit,'r-')
axis([0 5 0.6 1.4])
TE = sprintf('A = %0.4f\nC_a_t_t = %0.4f',p(1),p(2));
text(3,1.2,TE,'fontsize',12,'EdgeColor','k');
hold off

%% Water + Milk
vm = [1.56,1.26,1.11,1,0.94,0.92,0.85,0.82,0.8,0.78]'; %light intensity in
terms of voltage (V)

%Plot raw data
figure
plot(r,vm,'*');
title('V_p_p vs. Probe Distance in Milk')
xlabel('Distance (cm)')
ylabel('Intensity (V)')

%Non-linear curve fitting model
%fitting optical attenuation function to data
modelfun=@(p,r) p(1)*((exp(-p(2)*r))./(4*pi*r));
beta0 = [1 1];
ft=fitnlm(r,vm,modelfun,beta0)
r2 = [0:0.1:5];
yfit = feval(ft,r2);
p = ft.Coefficients.Estimate;
hold on
plot(r2,yfit,'r-')
```

```
axis([0 5 0.6 1.4])
TE = sprintf('A = %0.4f\nC_a_t_t = %0.4f',p(1),p(2));
text(3,1.2,TE,'fontsize',12,'EdgeColor','k');
hold off
```

Appendix B

Exponential Regression

```
%%  Water
clear;clc;close all
D=[0.5,1,1.5,2,2.5,3,3.5,4,4.5,5];                 % In cm
V_water=[1.14,1.08,1.04,0.98,0.94,0.91,0.89,0.87,0.86,0.85];   % In V
 plot(D,V_water,'*'),xlabel('Distance (cm)'),ylabel('V_p_p ( V
)'),title('Voltage vs. Probe Distance in Water')
%Parameter set up
[P,S]=polyfit(D,log(V_water),1);
m=P(1);
b=exp(P(2));
%Theoretical data set
D2=[0.05:0.01:5];
V_water2=b*exp(m*D2);
hold on
plot(D2,V_water2, 'b-');
%Trendline Equation
TE=sprintf(' V_p_p = %0.2f*e^{%0.2fr}',b,m);
text(2,1.1,TE, 'fontsize',15);
%Checking answer
V_theoretical=1.14*exp(-0.07.*D)
%Calculating R-squared value to see how well model fits data
R2 = 1 - (S.normr^2/(norm(V_water - mean(V_water))^2))

%% Milk
D=[0.5,1,1.5,2,2.5,3,3.5,4,4.5,5];                 % In cm
V_milk=[1.56,1.26,1.11,1,0.94,0.92,0.85,0.82,0.80,0.78];      % In V
 figure,
plot(D,V_milk,'*'),xlabel('Distance (cm)'),ylabel('V_p_p ( V
)'),title('Voltage vs. Probe Distance in Milk')
%Parameter set up
[P,S]=polyfit(D,log(V_milk),1);
m=P(1);
b=exp(P(2));
%Theoretical data set
D2=[0:0.01:5];
V_milk2=b*exp(m*D2);
hold on
plot(D2,V_milk2, 'b-');
%Trendline Equation
TE=sprintf(' V_p_p = %0.2f*e^{%0.2fr}',b,m);
text(2,1.15,TE, 'fontsize',15);
%Calculating R-squared value to see how well model fits data
R2 = 1 - (S.normr^2/(norm(V_milk - mean(V_milk))^2))
```