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IB Chemistry HL Period 6

Determining the Relationship between a Sunscreen's SPF and its Absorbency under Various Wavelengths of Ultraviolet Light

Introduction:

Sunscreen has commonly been used to prevent ultraviolet radiations from damaging our skin. It contains ingredients such as titanium dioxide or zinc oxide which absorb ultraviolet light. [1] In every bottle of sunscreen, there is an indication of its Sun Protection Factor (SPF) which is a measure of the sunscreen's protection, or absorption, from UVB. A sunscreen with an SPF of 20 would allow a person to not be burned by the sun 20 times longer than the amount of time that it would take to burn the same person without using sunscreen. [2]

A sunscreen's absorbance is the proportion of the light that is absorbed by the sunscreen. It can be represented by the equation:

Equation 1:
$$A_\lambda = \log_{10}(I_0/I)$$

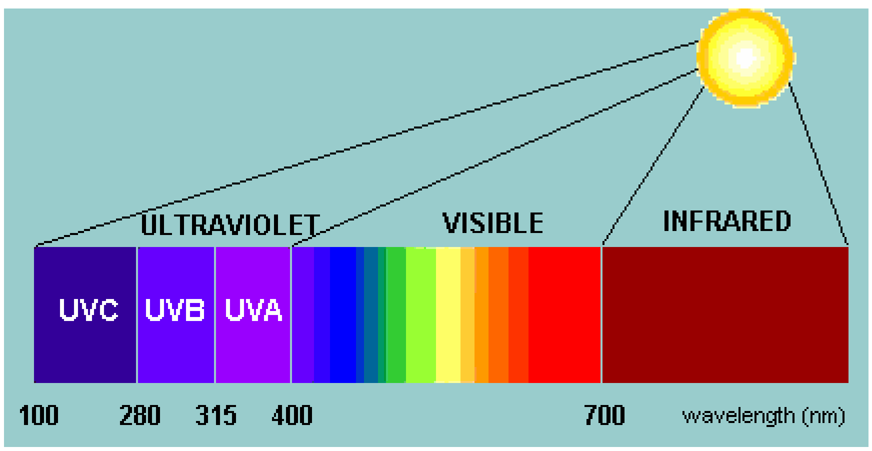


Figure 1: Wavelengths of various types of light [3]

Where A is the absorbance, I_o is the intensity of the light before it enters a sample and I is the intensity of the light that has passed through the sample [4]. The absorbance is proportional to the thickness of the sample tested and the concentration of the absorbing species in that sample. [4] As SPF is a measure of protection from UVB, it is based on ultraviolet light that has wavelengths from 280 to 315 nanometers. [Figure 1] If the sunscreen's absorbance was also tested under the other types of ultraviolet light, UVA (315 to 400 nanometers) and UVC (100 to 280 nanometers), how would the results vary when different SPFs are used? This leads to the research question: *How does the SPF of sunscreen affect its absorbency under various wavelengths of ultraviolet light?*

<u>Sources:</u>
[1] http://en.wikipedia.org/wiki/Sunscreen
[2] http://dermatology.about.com/cs/skincareproducts/a/spf.htm
[3] http://www.optimalhealthpartner.com/A_Newsletter/spectrum.gif
[4] http://en.wikipedia.org/wiki/Absorbance

Research Question:

How does the SPF of sunscreen affect its absorbency under various wavelengths of ultraviolet light?

Variables:

Independent variable: The independent variable in this experiment will be the SPF of the sunscreen.

Dependent variable: The dependent variable in this experiment will be the absorbance of the sample of sunscreen used.

Controlled variables: The controlled variables in this experiment will be the way the absorbance of the sunscreen is measured, the wavelengths of ultraviolet light used and the concentration of the sunscreen for the different SPFs.

Hypothesis:

Since the absorbance of a solution is proportional to its thickness and is the proportion of light that is absorbed by the solution, the sunscreen with the higher SPF would have a higher absorbance than a sunscreen with a lower SPF for a given wavelength of ultraviolet light. As based on Equation 1, if the intensity of the light before it enters the sample (I_o) were to be constant for the different SPFs and the intensity of the light that passes through the sample (I) were to vary with the SPFs, then the absorbance would increase as the SPF increases. I would get smaller as the SPF increases due to it being harder for the light to pass through a thicker sample. When I_o is divided by a smaller number for I, the result would be a larger number. When the absorbance is calculated by taking the log of the result, the absorbance would be higher for smaller values of I. Therefore, as SPF increases, the absorbance also increases.

Procedure:

A spectrophotometer was turned on, set to use ultraviolet light and allowed to warm up. A diluted solution of sunscreen with a SPF of 20 was prepared by placing a 1000.0 ± 0.6 milliliters volumetric flask on a high capacity balance with an uncertainty of ± 0.01 grams. The tare function was then used to set the mass on the balance to zero and 0.05 ± 0.01 grams of the sunscreen was then poured into the volumetric flask. Distilled water was then poured up to the 1000.0 ± 0.6 milliliter mark on the volumetric flask to dilute the solution. Two quartz cuvettes were then obtained. One cuvette was filled with distilled water and placed into one of the slots in the spectrophotometer. The other cuvette was filled with the diluted sunscreen solution and then placed into another slot inside the spectrophotometer. The wavelength on the spectrophotometer was then set to 220 nanometers and the machine was set to the absorbency setting. The spectrophotometer was then zeroed using the cuvette with distilled water. The absorbency of the cuvette containing sunscreen solution was then measured and recorded three times to obtain more accurate readings of the absorbency. Each time the absorbency was zeroed by using the cuvette with distilled water. This process was repeated five more times using other wavelengths including 240, 260, 280, 300 and 320 nanometers. The entire process was then repeated for the other sunscreens with a SPF of 30 and 50. For each SPF the same set of wavelengths, brand of sunscreen, spectrophotometer, concentration of 0.05 ± 0.01 grams of sunscreen/1000.0 ± 0.6 milliliters of distilled water and cuvette filled with distilled water was used to keep the readings consistent and controlled. Two additional trials were then performed using SPF 50 sunscreen with concentrations of 0.01 ± 0.01 grams of sunscreen/1000.0 ± 0.6 milliliters of distilled water and 0.04 ± 0.01 grams of sunscreen/1000.0 ± 0.6 milliliters of distilled water.

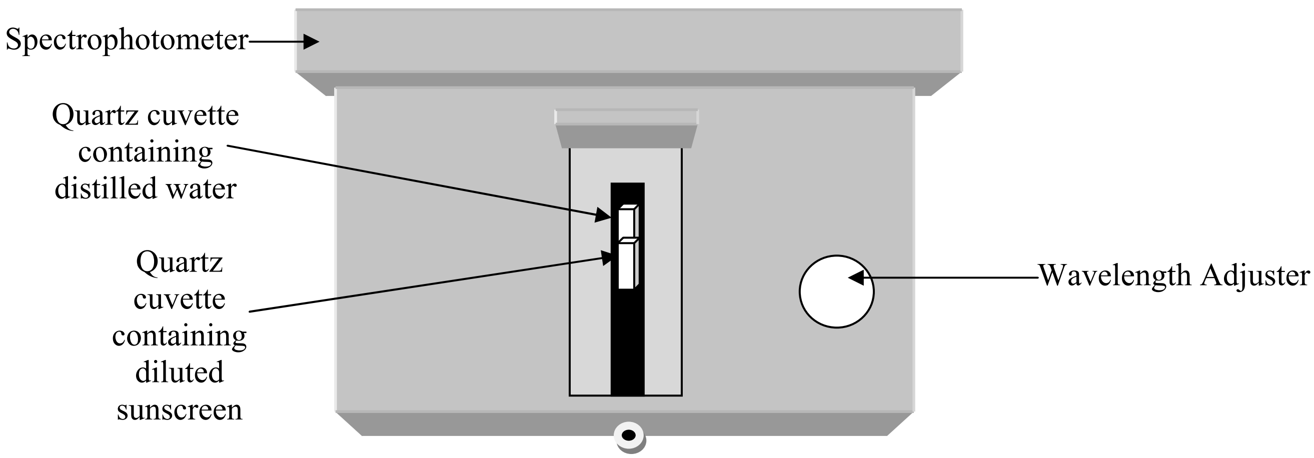


Figure 2: Set up of the investigation which includes two quartz cuvettes placed inside a spectrophotometer to be examined under a particular wavelength

Data Collection:

Table 1: Absorbance of 0.05 ± 0.01 grams/1000.0 ± 0.6 milliliters SPF 50 Sunscreen at Various Wavelengths

	Absorbance (± 0.008 units) at Various Wavelengths (± 1 nanometer)					
Trials	**220**	**240**	**260**	**280**	**300**	**320**
1	0.467	0.486	0.385	0.401	0.470	0.387
2	0.467	0.502	0.386	0.399	0.469	0.383
3	0.467	0.501	0.385	0.398	0.473	0.382

Table 1 shows the absorbance of the diluted SPF 50 sunscreen under the various wavelengths for all of the trials. The uncertainty of the mass, ± 0.01 grams was observed on the high capacity balance, while the uncertainty of the volume of the diluted solution was observed of the volumetric flask. The uncertainty of the absorbance readings, ± 0.008 units was calculated by taking half the range of the values for all the trials. The largest uncertainty was then used. The uncertainty of wavelengths was ± 1 nanometer as calculated by taking half of the smallest reading.

Table 2: Absorbance of 0.05 ± 0.01 grams/1000.0 ± 0.6 milliliters SPF 30 Sunscreen at Various Wavelengths

	Absorbance (± 0.008 units) at Various Wavelengths (± 1 nanometer)					
Trials	**220**	**240**	**260**	**280**	**300**	**320**
1	0.245	0.301	0.238	0.254	0.276	0.217
2	0.240	0.298	0.235	0.256	0.277	0.217
3	0.242	0.300	0.239	0.257	0.278	0.218

Table 2 shows the absorbance of the diluted SPF 30 sunscreen under the various wavelengths for all of the trials. The uncertainty values were derived using the methods discussed in Table 1.

Table 3: Absorbance of 0.05 ± 0.01 grams/1000.0 ± 0.6 milliliters SPF 20 Sunscreen at Various Wavelengths

	Absorbance (± 0.008 units) at Various Wavelengths (± 1 nanometer)					
Trials	**220**	**240**	**260**	**280**	**300**	**320**
1	0.168	0.228	0.172	0.177	0.178	0.117
2	0.173	0.229	0.171	0.176	0.182	0.116
3	0.172	0.226	0.173	0.173	0.177	0.118

Table 3 shows the absorbance of the diluted SPF 20 sunscreen under the various wavelengths for all of the trials. The uncertainty values were derived using the methods discussed in Table 1.

Table 4: Absorbance (± 0.008 units) of Various Concentrations of SPF 50 at a Wavelength of 280 ± 1 Nanometers

	Concentration (± 0.01 grams /± 0.6 milliliters)		
Trials	**0.01/1000.0**	**0.04/1000.0**	**0.05/1000.0**
1	0.115	0.323	0.401
2	0.114	0.316	0.399
3	0.117	0.317	0.398

Table 4 shows the absorbance of the different concentrations of the diluted SPF 50 sunscreen under a wavelength of 280 ± 1 nanometer for all of the trials. The uncertainty values were derived using the methods discussed in Table 1.

Data Analysis:

Sample Calculation of the Concentration of Diluted Sunscreen:
Concentration = 0.05 grams/ 1000.0 milliliters = 0.00005 grams/milliliters
Uncertainty = (Percent uncertainty of mass + percent uncertainty of volume) * Concentration
= (0.01/0.05 + 0.6/1000.0) * 0.00005
= (0.2 + 0.0006) * 0.00005
= (0.2006) * 0.00005
≈ 0.00001
Concentration = 0.00005 ± 0.00001 grams/milliliters

Table 5: Average Absorbance under Various Wavelengths for all SPFs of Sunscreen used with a Concentration of 0.00005 ± 0.00001 grams/milliliters

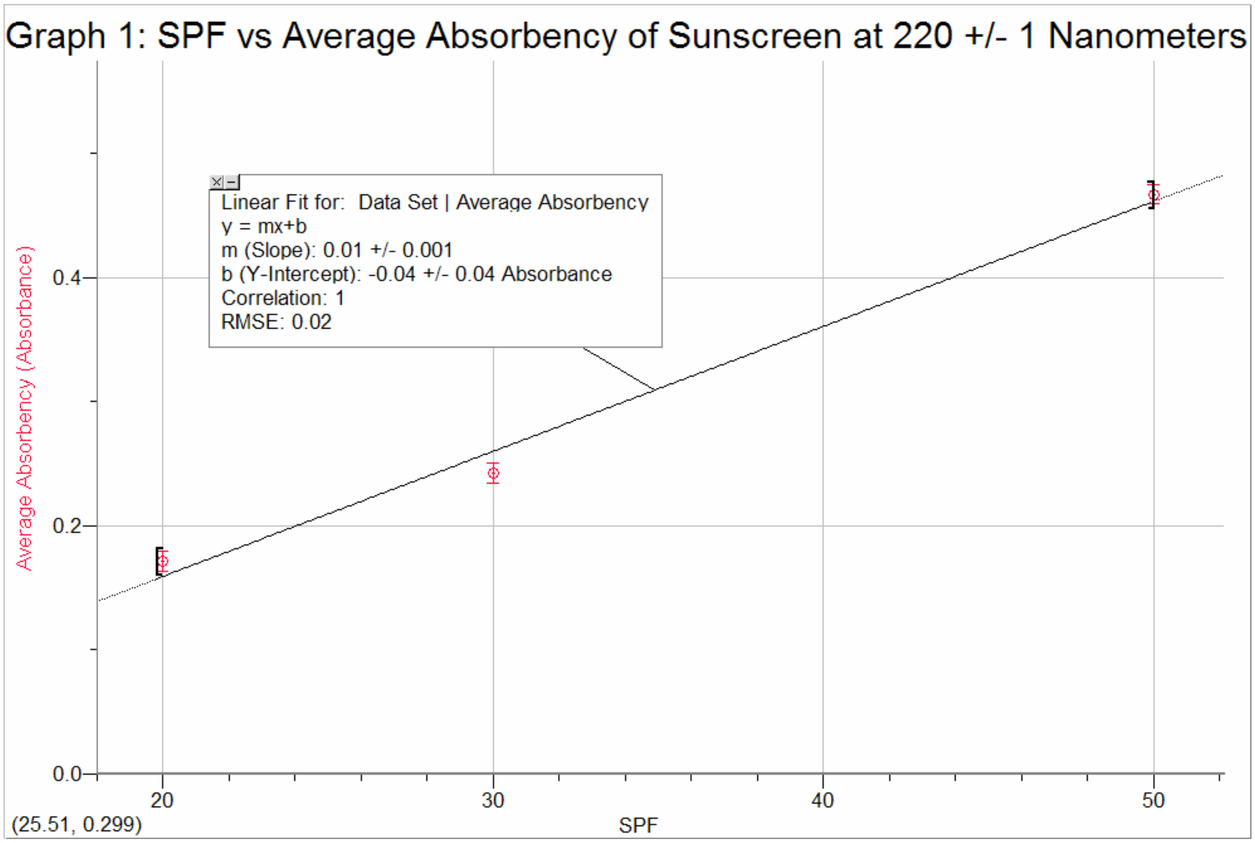
SPF	Average Absorbency (± 0.008) of 220 ± 1 nanometers	Average Absorbency (± 0.008) of 240 ± 1 nanometers	Average Absorbency (± 0.008) of 260 ± 1 nanometers	Average Absorbency (± 0.008) of 280 ± 1 nanometers	Average Absorbency (± 0.008) of 300 ± 1 nanometers	Average Absorbency (± 0.008) of 320 ± 1 nanometers
20	0.171	0.228	0.172	0.175	0.179	0.117
30	0.242	0.300	0.237	0.256	0.277	0.217
50	0.467	0.496	0.385	0.399	0.471	0.384

Table 5 shows the average absorbance under each of the wavelengths for all of the SPFs of sunscreen. The uncertainty values were derived using the methods discussed in Table 1.

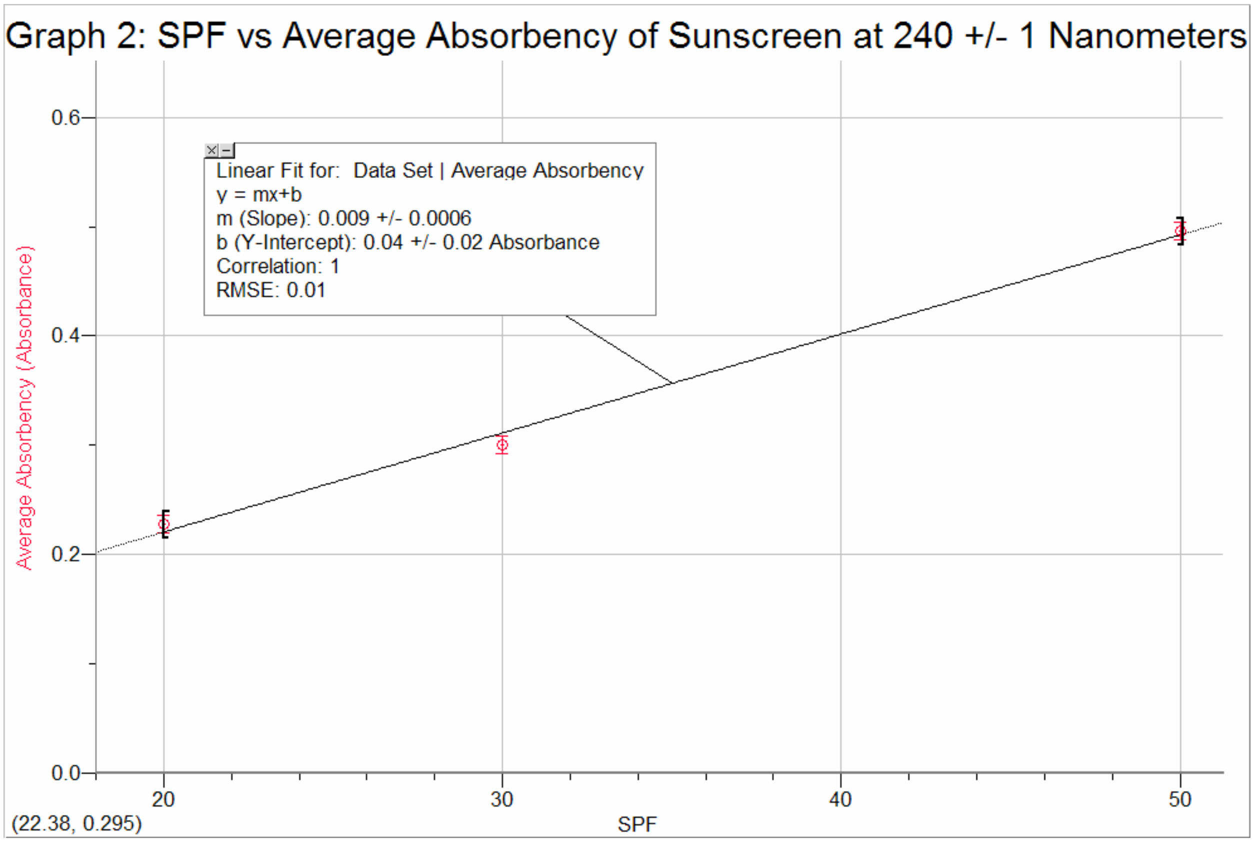
Table 6: Average Absorbency of Sunscreen of SPF 50 with Various Concentrations at a Wavelength of 280 ± 1 Nanometers

Concentration (± 0.00001 grams/milliliters)	0.00001	0.00004	0.00005
Average Absorbance (± 0.008)	0.115	0.319	0.399

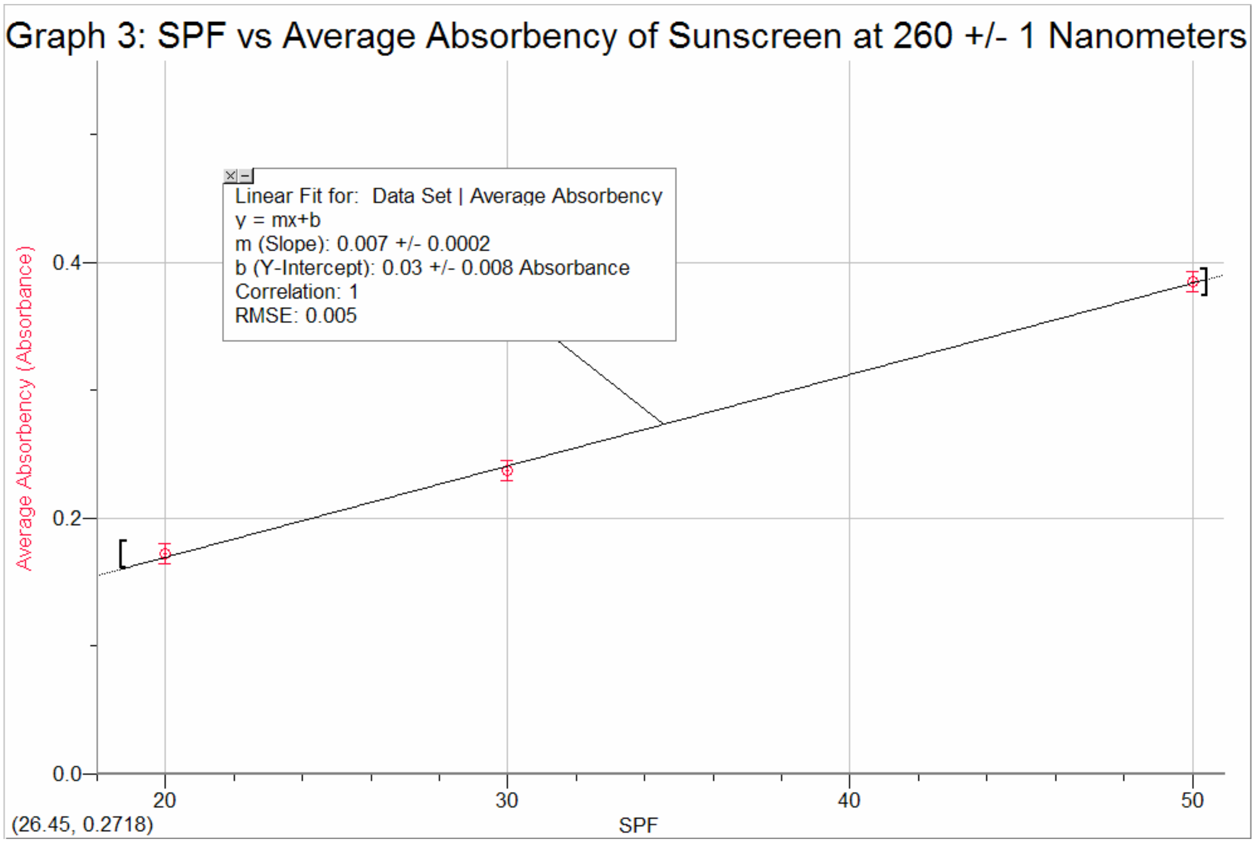
Table 6 shows the average absorbance of sunscreen of SPF 50 under a wavelength of 280 ± 1 nanometer for the various concentrations. The uncertainty values were derived using the methods discussed in Table 1.



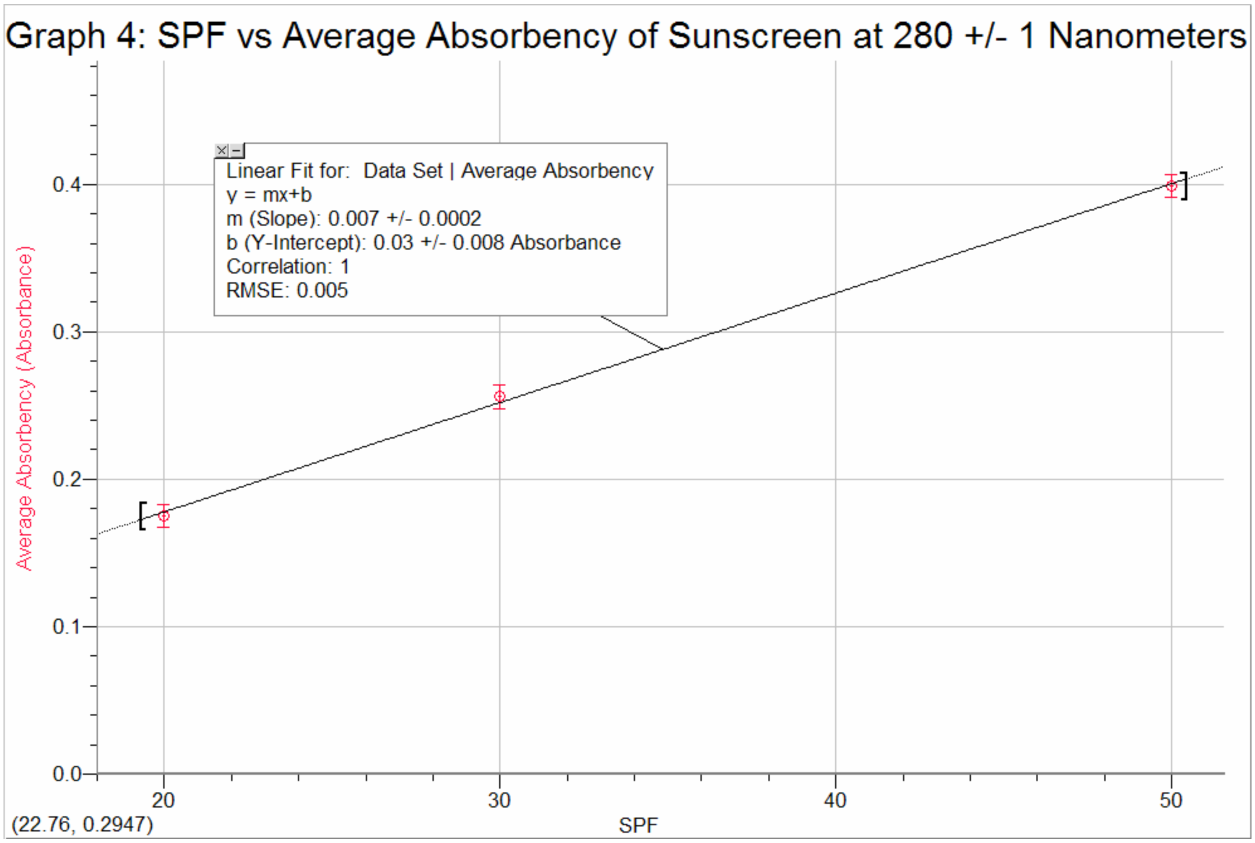
Graph 1 displays the values in Table 5 for a wavelength of 220 ± 1 nanometers. As shown, the slope is 0.010 ± 0.001 absorbance/SPF and corresponds to the rate that the absorbance changes when the SPF changes. The y-intercept, -0.04 ± 0.04 absorbance, would be the absorbency at 0 SPF.



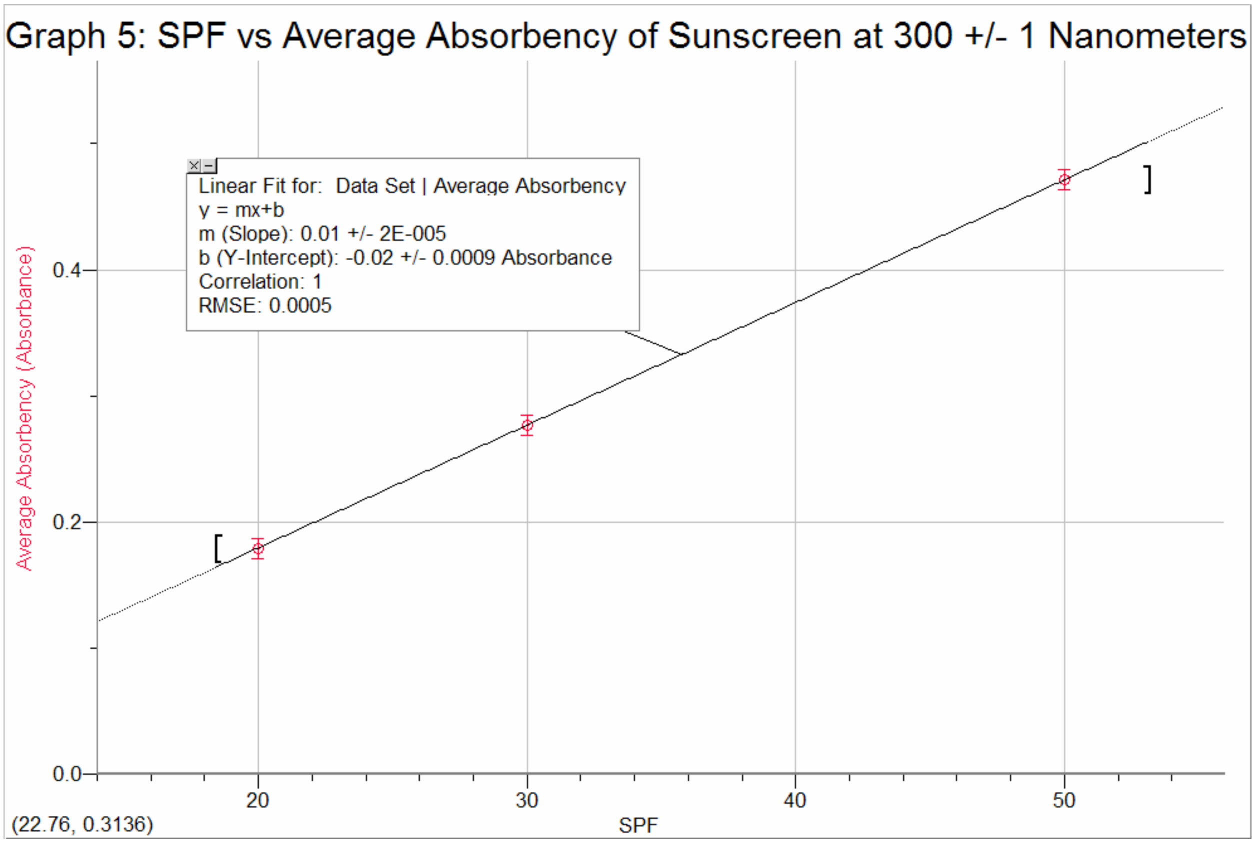
Graph 2 displays the values in Table 5 for a wavelength of 240 ± 1 nanometers. As shown, the slope is 0.0090 ± 0.0006 absorbance/SPF and corresponds to the rate that the absorbance changes when the SPF changes. The y-intercept, 0.04 ± 0.02 absorbance, would be the absorbency at 0 SPF.



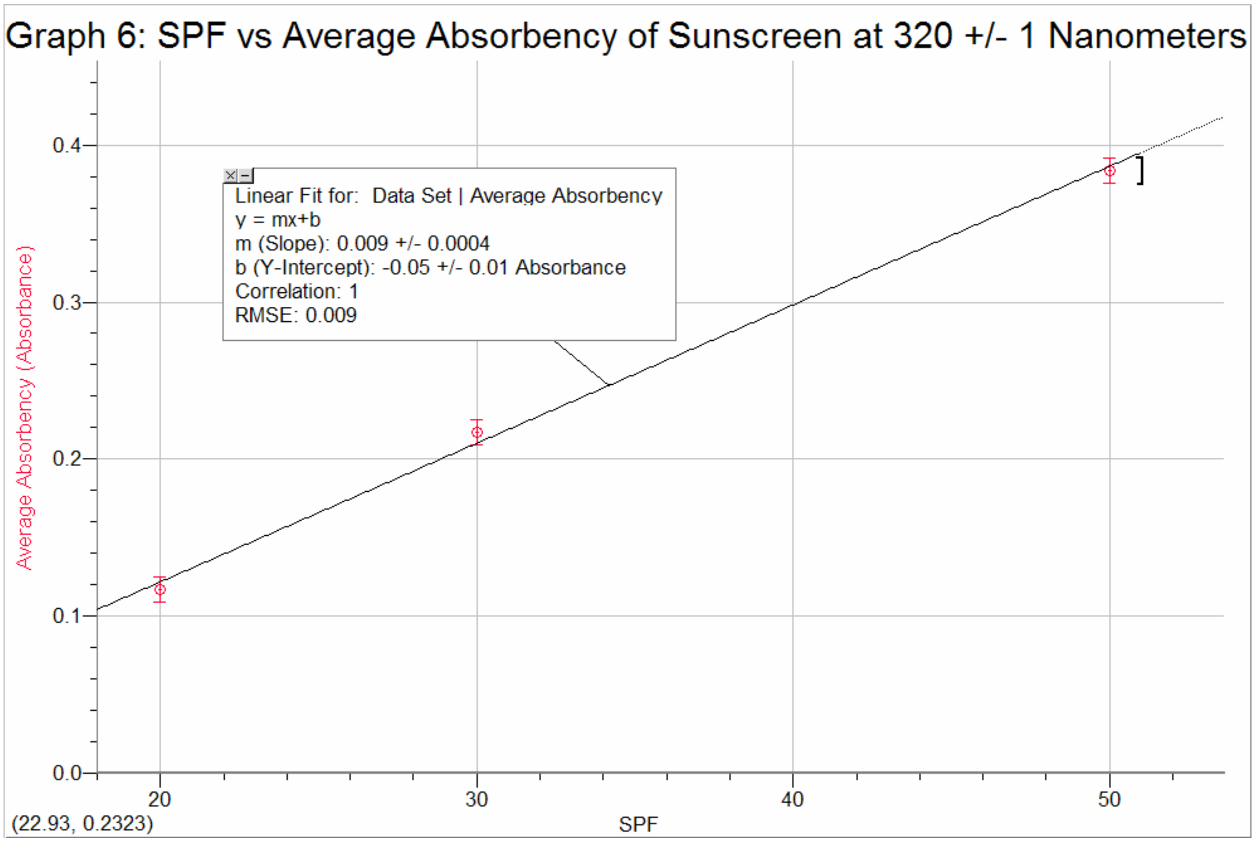
Graph 3 displays the values in Table 5 for a wavelength of 260 ± 1 nanometers. As shown, the slope is 0.0070 ± 0.0002 absorbance/SPF and corresponds to the rate that the absorbance changes when the SPF changes. The y-intercept, 0.030 ± 0.008 absorbance, would be the absorbency at 0 SPF.



Graph 4 displays the values in Table 5 for a wavelength of 280 ± 1 nanometers. As shown, the slope is 0.0070 ± 0.0002 absorbance/SPF and corresponds to the rate that the absorbance changes when the SPF changes. The y-intercept, 0.030 ± 0.008 absorbance, would be the absorbency at 0 SPF.



Graph 5 displays the values in Table 5 for a wavelength of 300 ± 1 nanometers. As shown, the slope is 0.01000 ± 0.00002 absorbance/SPF and corresponds to the rate that the absorbance changes when the SPF changes. The y-intercept, -0.0200 ± 0.0009 absorbance, would be the absorbency at 0 SPF.



Graph 6 displays the values in Table 5 for a wavelength of 320 ± 1 nanometers. As shown, the slope is 0.0090 ± 0.0004 absorbance/SPF and corresponds to the rate that the absorbance changes when the SPF changes. The y-intercept, -0.05 ± 0.01 absorbance, would be the absorbency at 0 SPF.

Table 7: Slopes and Y-intercepts of Equations given by Various Wavelengths

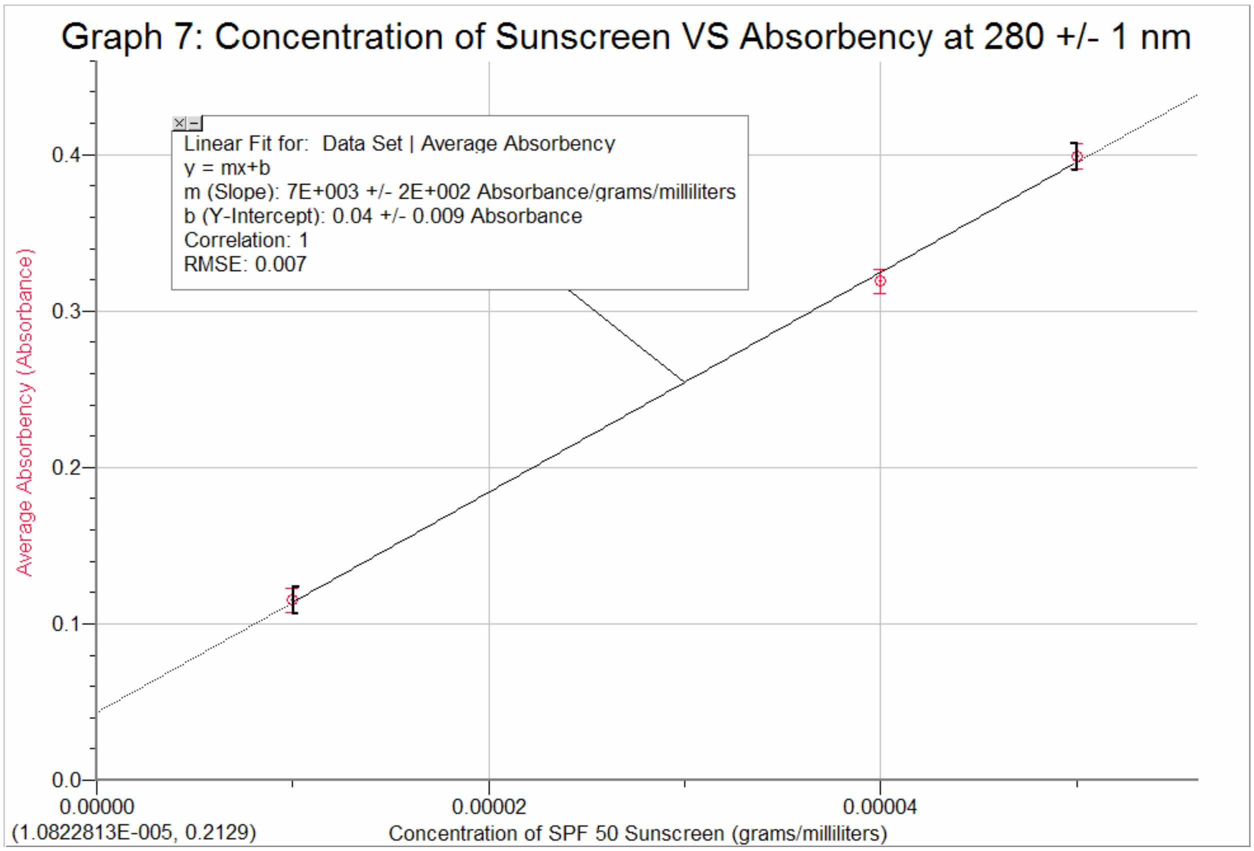
Wavelengths (± 1 nanometer)	220	240	260	280	300	320
Slope of Equation (± 0.001 absorbance/SPF)	0.010	0.009	0.007	0.007	0.010	0.009
Y-intercept of Equation (± 0.02 absorbance)	-0.04	0.04	0.03	0.03	-0.02	-0.05

Table 7 summarizes the slopes and y-intercepts of the lines in Graphs 1 to 6. The largest uncertainty for the slopes and y-intercepts is shown.

Table 8: Average of the Slopes and Y-intercepts of the Equations given by Various Wavelengths

Average of the Slopes of the Equations (± 0.002 absorbance /SPF)	0.009
Average of the Y-intercept of the Equations (± 0.05 absorbance)	0.00

Table 8 shows the average of the slopes and y-intercepts of the lines in Graphs 1 to 6. The uncertainties were calculated by taking half the range of the values.



Graph 7 displays the values in Table 6. As shown, there is a direct relationship between the concentration of the SPF 50 solution and the absorbency. As the concentration increases, the absorbency also increases.

Conclusion:

As shown on Graphs 1 to 6, the hypothesis was supported. The hypothesis stated that the absorbance of a solution of sunscreen would increase as the SPF of the sunscreen increases. The results of this investigation have supported the hypothesis, as shown by the equation of the line produced by using the values in Table 8:

Equation 2: $A = (0.009 \pm 0.002\ S) + (0.00 \pm 0.05)$,
Where A is the absorbance of the sunscreen in absorbance units and S is the SPF of the sunscreen.

Deriving Equation 2, by averaging the slopes of the graphs at various wavelengths therefore supports the hypothesis. The positive slope suggests that the absorbance of the sunscreen solution would increase as the SPF of the solution increases. The results of this research are also somewhat strong as supported by Graph 7. As the concentration of the solution of sunscreen increases, the absorbency also increases. This supports the hypothesis that a thicker or more concentrated solution would cause an increase in absorbance proportionally. Furthermore, the values in Graphs 1 to 6 are also within the uncertainty bars. The investigation is however limited to the use of NIVEA sunscreen. Performing the experiment using a concentration of 0.00005 ± 0.00001 grams/milliliters at wavelengths of 220 to 320 ± 1 nanometers was also a limitation.

Evaluation:

There were many weaknesses in this investigation. One weakness was that the spectrophotometer may not have been completely warmed up when the lab was performed. This would have caused a random error in the readings. To improve this error, the spectrophotometer should have been left for approximately 30 minutes after being turned on. Another weakness was that there were only two quartz cuvettes. This meant that in order to perform each trial, the cuvettes had to be cleaned, however there may have been visible traces of the remaining solution. This error would cause random results and can be improved by carefully cleaning the cuvettes using cotton buds. Another weakness in this investigation is that although the sunscreen used was from the same brand, the ingredients varied between the different SPFs. This caused a random error and can be improved by finding a brand that sells sunscreen, or making sunscreen, with the same ingredients but for different SPFs.