Abstract

In this experiment, we measured the concentration of a colorful soluble compound in water using its light absorption properties, as described by the Beer-Lambert Law. Betadine was chosen as the soluble compound. First, we captured the spectrum of the light source through a transparent bottle filled with water using a CD spectrometer. Subsequently, small portions of Betadine were added to the bottle, and the spectrum was captured after each addition, repeating the process five times. Python software was employed to measure the intensity at certain wavelengths for each spectrum, and a graph of absorbance versus wavelength was plotted using Octave software. This graph was then utilized to predict the unknown concentration of Betadine in a solution. The experiment assumes that water does not absorb light, and it is critical that the optical path length, as well as the distances between the light source, bottle, and spectrometer, remain constant during measurements.

Methodology

- Apparatus and accessories
  1. A transparent bottle (cuboid shape)
  2. Colorful liquid (liquid betadine)
  3. Water
  4. A light source (CFL bulb)
  5. CD Spectrometer
  6. Mobile phone with camera

- Procedure

1. Prepare the Solution:
   - Fill the transparent bottle with a known volume of water (400 cm^3) and place it on a table.

2. Setup the Equipment:
   - Position the light source (CFL bulb) behind the bottle and place the spectrometer in front of the bottle.

3. Capture Initial Spectra:
   - Capture five images of the spectrum of the light source through the bottle filled with water. The intensity of each wavelength in this spectrum is taken as the incident intensity (I_0).

4. Add Betadine:
   - Add 0.5 ml of colorful liquid (Betadine) to the bottle and mix it thoroughly to ensure uniform concentration throughout the solution.

5. Capture Absorbance Spectra:
   - Capture five images of the spectrum of the light source through the Betadine solution. Label these spectra as spectrum 1.1, 1.2, 1.3, etc. These spectra are known as absorbance spectra. The concentration of Betadine in the solution can be calculated by dividing the Betadine volume by the total volume.

6. Increase Concentration:
   - Add another 0.5 ml portion of Betadine and capture five images of the absorbance spectrum. Label these as spectrum 2.1, 2.2, etc.

7. Repeat for Multiple Concentrations:
   - Repeat step 6 for at least five different concentrations.

8. Analyze Initial Spectra:
   - Insert the spectra captured in step 3 into the calibrated Python code relevant to the CD spectrometer.

- Select a wavelength (λ) with an intensity peak and measure the intensity (I_0). Repeat this for the other four images and calculate the average intensity. Red or green color intensity peaks are more suitable for Betadine.

9. Analyze Absorbance Spectra:
   - Using spectrum 1.1, measure the intensity (I_n) of the selected wavelength (λ) from step 8. Repeat this for the other four images (1.2, 1.3, etc.) and calculate the average intensity.

10. Repeat for All Spectra:
    - Repeat step 9 for all other absorbance spectra.

11. Plot Data:
    - Using the data obtained, plot the graph of absorbance versus concentration.

By following these steps, you can accurately measure the concentration of Betadine in a solution using its light absorption properties and the Beer-Lambert Law.

Calculating an Unknown Concentration

1. Capture Absorbance Spectrum:

   - Capture the absorbance spectrum of a Betadine solution with an unknown concentration.

2. Measure Peak Intensity:

   - Use the previous steps to measure the peak intensity of the selected wavelength (λ).

3. Calculate Absorbance:

   - Calculate the absorbance (A) using the formula:

$$A = \log(\frac{I_0}{I_n})$$

   where I_o is the incident intensity (measured from the initial spectrum) and I_n is the intensity of the peak from the unknown concentration spectrum.

4. Determine Concentration:

   - Use the previously plotted graph of absorbance versus concentration to find the concentration corresponding to the measured absorbance.

By following these steps, you can accurately determine the unknown concentration of Betadine in the solution.

Figure Panel

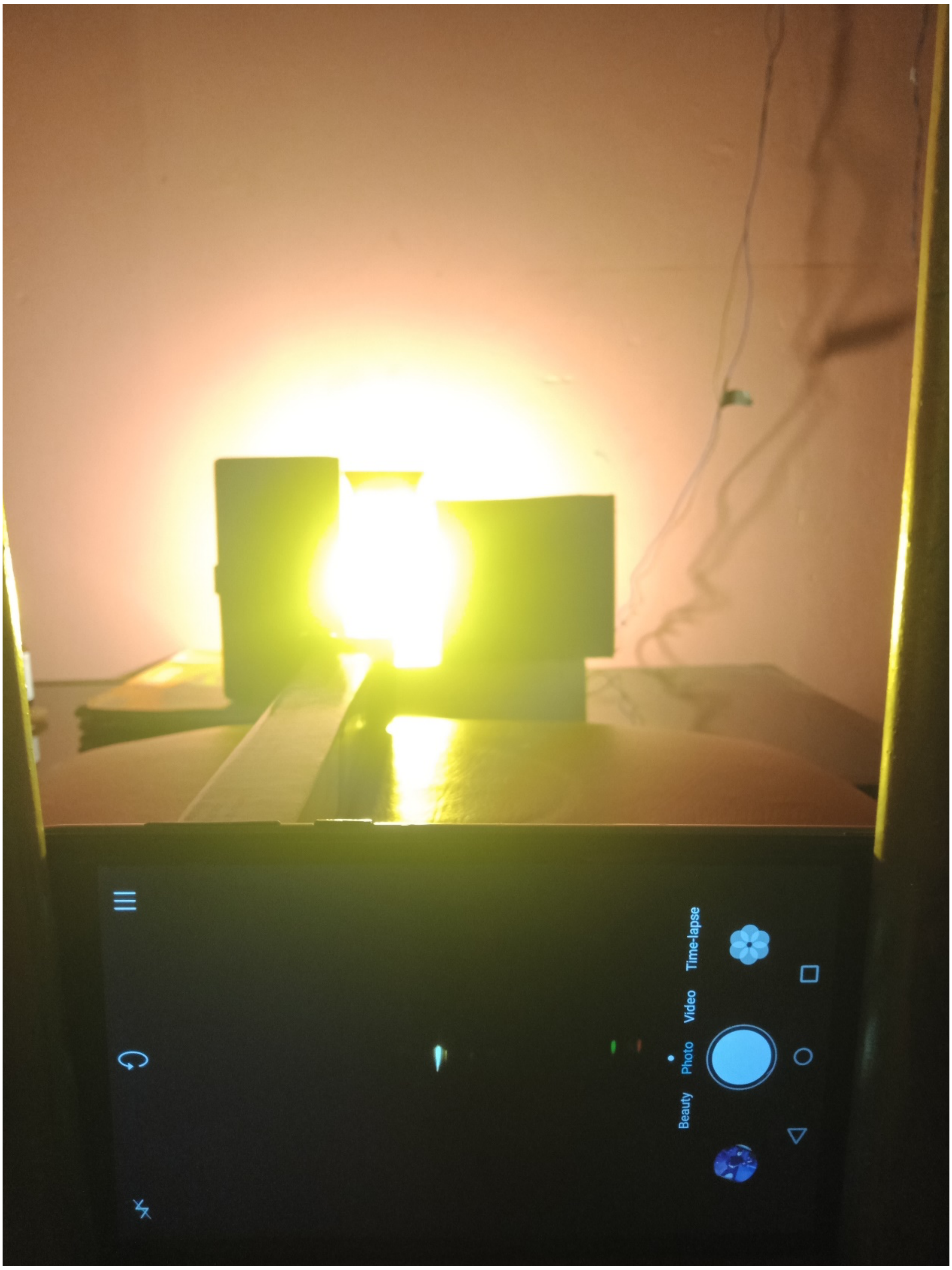
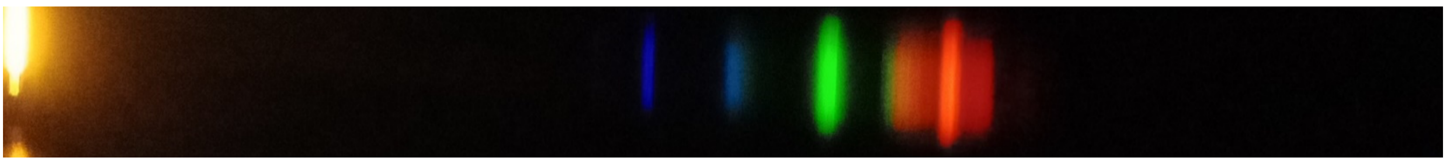


Figure 1.a: An image of the experimental apparatus. The positions of the light source, the bottle containing the solution, and the spectrometer are fixed and cannot be changed.

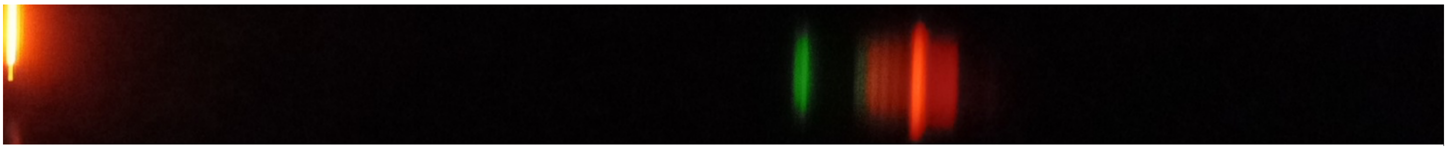
Figure 1.b: This is also an image of the experimental apparatus. Performing the experiment in a dark room provides more accurate measurements, as light enters the spectrometer only through the bottle.



Spectrum 1

Spectrum 3

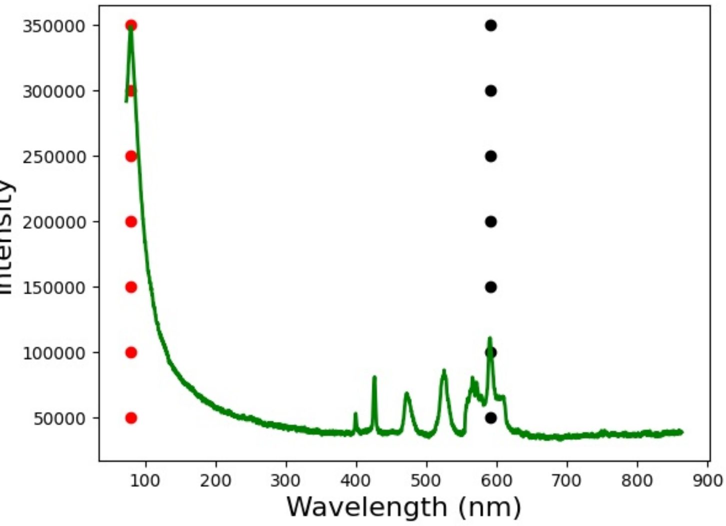
Spectrum 2



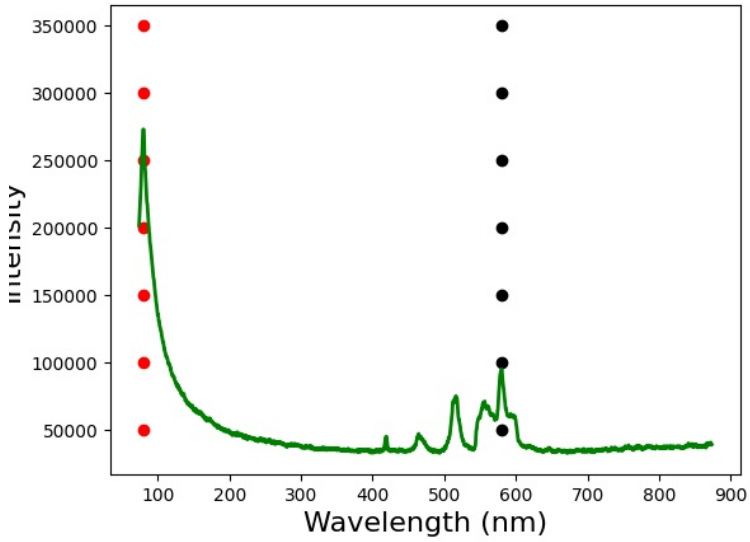
Spectrum 4

Spectrum 5

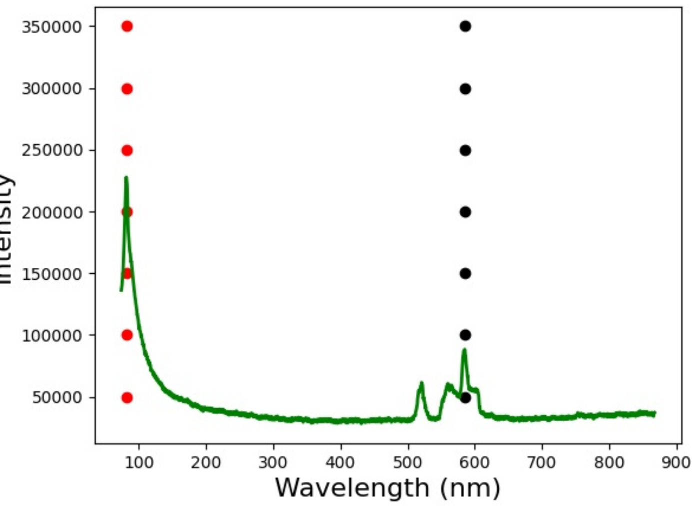
Figure 2: These are the absorbance spectra. From spectrum 1 to spectrum 5, the concentration increases, and absorbency also increases. Spectrum 1 shows many color lines, while from spectrum 3 onward, there are only two spectrum lines. Absorbance increases rapidly even with a small increase in concentration..



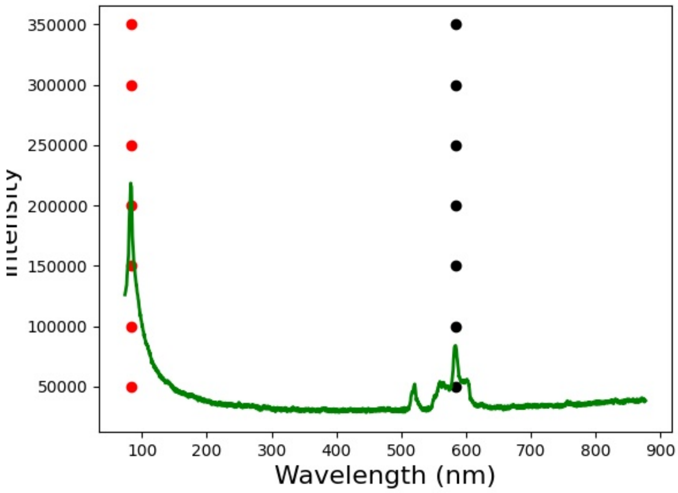
Spectrum Graph 1



Spectrum Graph 2



Spectrum Graph 3



Spectrum Graph 4

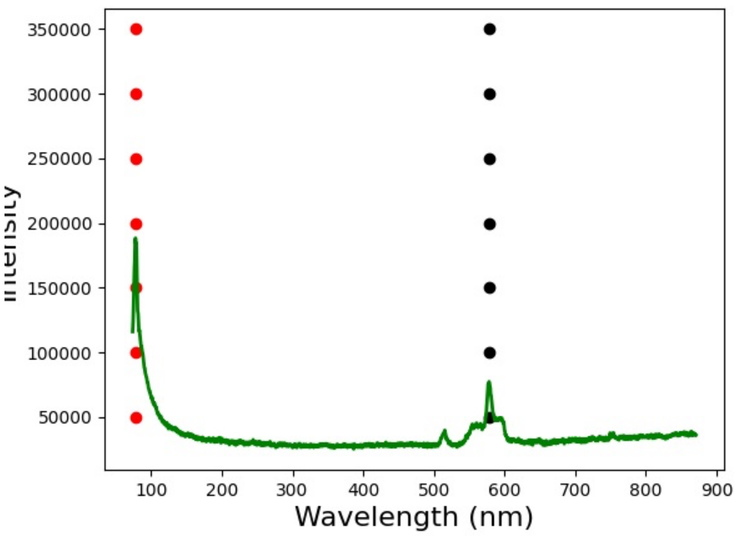


Figure 3: In the intensity vs. wavelength graphs shown above, the red dotted line corresponds to the slit, where intensity is at its maximum. The black dotted line corresponds to the intensity peak at 578 nm. Betadine concentration increases

from graph 1 to graph 5, and the intensity peak at 578 nm decreases from graph 1 to graph 5.

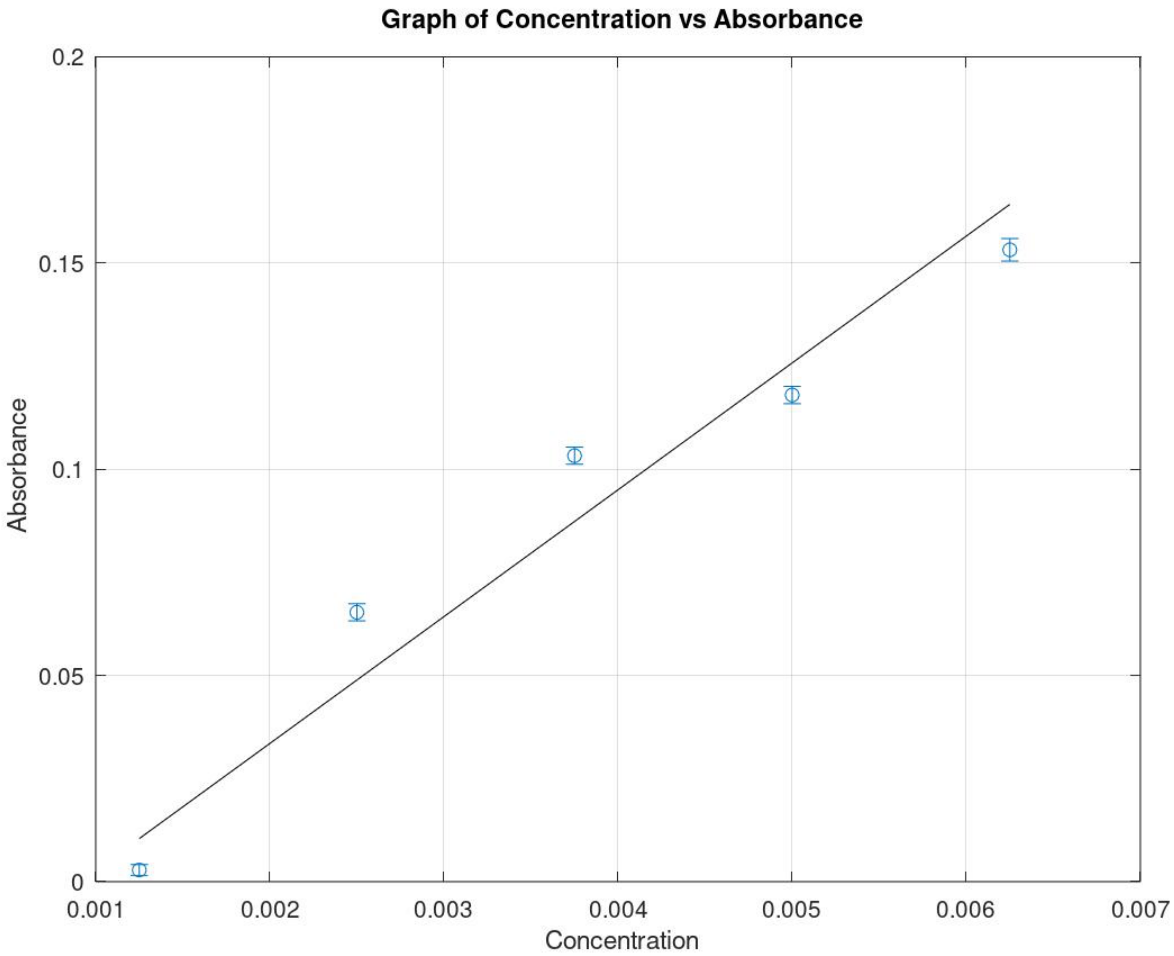


Figure 4: This graph was obtained using Octave software. It illustrates the relationship between concentration and absorbance.

Appendix

Intensity values of peak points and corresponding absorbance

Added betadine volume	**Only with water**	**0.5 ml**	**1.0 ml**	**1.5 ml**	**2.0 ml**	**2.5 ml**
	110306	110292	94662	87708	83443	76998
	111443	110431	94338	86494	83803	77458
	110220	109752	96091	88067	85263	77350
	110184	109954	95079	86460	84821	77767
	111521	109659	96184	87740	84611	79503
Average	**110734.8**	**110017.6**	**95270.8**	**87293.8**	**84388.2**	**77815.2**
Standard deviation	684.0918798	335.1780124	834.29653	758.8472837	748.0128341	982.701735
Standard error	305.9351892	149.8961641	373.1087509	339.3668222	334.521509	439.4775762

$$I_0 = 110735$$

Absorbance can be calculated by using equation given below

$$Absorbance\ (A) = \log\left(\frac{I_0}{I}\right)$$

For spectrum 1 (0.5 ml betadine)

$$A_1 = \log\left(\frac{110735}{110017}\right) = 0.0028212$$

For spectrum 2

$$A_2 = \log\left(\frac{110735}{95271}\right) = 0.0653242$$

For spectrum 3

$$A_3 = \log\left(\frac{110735}{87294}\right) = 0.1033005$$

For spectrum 4

$$A_4 = \log\left(\frac{110735}{84388}\right) = 0.1180042$$

For spectrum 5

$$A_5 = \log\left(\frac{110735}{77815}\right) = 0.1532215$$

Error of absorbance

$$\delta A = \left(\boldsymbol{\frac{\partial A}{\partial I_0}}\right)^{\mathbf{2}} (\boldsymbol{\delta I_0})^{\mathbf{2}} + \left(\boldsymbol{\frac{\partial A}{\partial I}}\right)^{\mathbf{2}} (\boldsymbol{\delta I})^{\mathbf{2}}$$

$$\frac{\partial A}{\partial I} = \frac{\frac{1}{I}}{\frac{I_0}{I}(ln10)} = \frac{1}{I_0(ln10)}$$

$$\frac{\partial A}{\partial I} = -\frac{\frac{I_0}{I^2}}{\frac{I_0}{I}(ln10)} = -\frac{1}{I(ln10)}$$

$$\delta A = \left(\frac{1}{ln10}\right)^2 \left(\left(\frac{\delta I_0}{I_0}\right)^2 + \left(\frac{\delta I}{I}\right)^2\right)$$

For A_1

$$\delta A_1 = \left(\frac{1}{ln10}\right)^2 \left(\left(\frac{306}{110734}\right)^2 + \left(\frac{150}{110018}\right)^2\right) = 0.001338$$

Absorbance and corresponding error values

absorbance	Error
0.0028212	0.001338
0.0653242	0.002081
0.1033005	0.0020699
0.1180042	0.0020964
0.1532215	0.002728

Calculating Concentration

Concentration of the betadine when add 0.5 ml portion of betadine into 400ml water = c_1

$$c_1 = \frac{betadine\ volume}{total\ volume.}$$

Betadine volume is very small compare to the water volume. Therefore total volume = water volume

$$c_1 = \frac{0.5\ ml}{400\ ml} = \frac{1.25\ ml}{1000\ ml} = 0.00125\ ml\ dm^{-3}$$

Concentration and corresponding absorbance values

concentration	absorbance	Error
0.00125	0.0028212	0.001338
0.00250	0.0653242	0.002081
0.00375	0.1033005	0.0020699
0.00500	0.1180042	0.0020964
0.00526	0.1532215	0.002728

Gradient of the graph (m) = 30.7 ± 0.5

absorbance A = mc

A = 30.7 C ------ 1

Any unknown concentration of betadine in water can be calculated by equation 1.

Calculating unknown concentration

Intensity of the unknown spectrum with wavelength (λ)

$$I = \frac{71610 + 70216 + 70462 + 75182 + 71814}{5}$$

$$I = 71856$$

$$I_0 = 110735$$

$$A = \log\left(\frac{I_0}{I}\right)$$

$$A = \log\left(\frac{110735}{71856}\right) = 0.1878$$

1 ➔

$$C = \frac{A}{30.7} = \frac{0.1878}{30.7} = 0.006117\ ml\ dm^{-3}$$