Optical Activity of Sugar

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I. INTRODUCTION

Understanding how the concentration of sugar in solution has practical applications in medicine. Currently, testing blood-sugar levels requires drawing a small blood sample for chemical testing. An application of research into the effect of solution sugar concentration on light polarization would be for testing blood sugar levels in diabetics non-invasively.

The method used to polarize a white-light source consisted of two Polaroid polarizers: an individual polarizer produces linearly polarized light by selective absorption. More specifically, our method used two polarizers to determine both the polarization of light entering the solution beaker and the light exiting the solution beaker. Knowing both these polarizations allowed us to determine the change in polarization through the solution beaker.

II. METHODS

In order to understand how sugar concentration in water affects the polarization of light, we measured the intensity of light exiting a second, constant angle polarizer as a function of the angle of the first polarizer. We used a bright white light source, a photometer, and a series of beakers varying in size with different concentrations of sugar in water. By using two polarizers, one at a constant angle and the other at varying angles, we were able to determine the relative polarization change by the sugar water. For each trial, the first (varying) polarizer began at 90 degrees to the second (constant) polarizer, and was then rotated in 10 degree increments to 0 degrees relative to the constant polarizer. We first began by measuring the intensity of light exiting the second polarizer for no beaker, then small, medium, and large beakers with no water. This initial dataset provided us with a baseline for the intensity of light exiting the second polarizer.

There were several possible sources of uncertainty unrelated to error in measurement. The first was the use of external light sources. A phone flashlight was used to see the angle of the polarizer and the intensity meter. Although the phone flashlight was necessary to make measurements, its effect on the intensity meter could have been minimized by shielding the fiber optic cable from the flashlight's light.

A secondary source of uncertainty could be the swirling of the solution in the beaker. The swirling of the solution could have caused light to scatter unevenly, leading to either higher or lower intensity readings. The possible source of uncertainty stemming from the swirling of the solution could have been minimized by allowing the solution to settle longer prior to taking measurements.

A tertiary source of uncertainty could be the amount of light traveling through each differently sized beakers directly into the fiberglass optical cable. We are unsure if there would be any direct way to minimize the possible uncertainty stemming from the amount of light traveling through each differently sized beaker. However, this uncertainty can be discarded when comparing intensity measurements between trials with the same beaker size.

A final possible source of uncertainty stemmed from the medium beaker being broken and needing to be replaced prior to the solution 2 experiment. Although unlikely, the replacement beaker could have had slightly different optical properties than the original medium beaker.

III. DATA AND RESULTS

Solution	Mass ± 0.1 (g)	Volume ± 2 (mL)	Concentration ± 0.001 (g/mL)
1	100.20	1000.00	0.10
2	200.20	1003.00	0.20
3	150.60	1000.00	0.15
4	75.30	1000.00	0.07

TABLE 1. Data for sugar solution concentrations with mass measured in grams, volume measured in milileters, and concentration measured in grams per milileter.

Beaker Label	Beaker Diameter ± 0.1 (mm)
Small	69.90
Medium	88.80
Large	108.80

TABLE 2. Data for the diameters of each beaker size in milimeters for later use in path length plots.

Polarization (degrees)	Intensity (arb. units)	Intensity ± (arb. units)
	No Beaker	
90	0.00	0.10
80	0.14	0.10
70	0.47	0.10
60	1.00	0.30
50	1.65	0.30
40	2.40	0.30
30	3.00	1.00
20	3.40	1.00
10	3.60	1.00
0	3.80	1.00
	Small Beaker	
90	0.00	0.10
80	0.05	0.10
70	0.40	0.10
60	0.78	0.10
50	1.25	0.30
40	1.75	0.30
30	2.20	0.30
20	2.55	0.30
10	2.70	0.30
0	2.85	0.30
	Medium Beaker	
90	0.00	0.10
80	0.12	0.10
70	0.47	0.10
60	0.94	0.10
50	1.50	0.30
40	2.10	0.30
30	2.65	0.30
20	3.00	1.00
10	3.20	1.00
0	3.30	1.00
	Large Beaker	
90	0.00	0.10
80	0.10	0.10
70	0.37	0.10
60	0.80	0.10
50	1.30	0.30
40	1.80	0.30
30	2.25	0.30
20	2.50	0.30
10	2.80	0.30
0	2.90	0.30

TABLE 3. Data for the no beaker, small beaker, medium beaker, and large beaker without water. The polarization was measured in degrees, and both intensity and intensity error were measured in arbitrary units.

Polarization (degrees)	Intensity (arb. units)	Intensity ± (arb. units)
	Small Beaker	
90	0.880	0.010
80	2.650	0.010
70	6.200	0.030
60	12.000	0.030
50	18.000	0.100
40	25.500	0.100
30	31.000	0.100
20	35.000	0.100
10	38.000	0.100
	Medium Beaker	
0	39.000	0.100
90	0.270	0.010
80	0.880	0.010
70	2.500	0.030
60	4.600	0.100
50	7.400	0.100
40	10.000	0.300
30	12.500	0.300
20	14.500	0.300
10	15.500	0.300
0	16.000	0.300
	Large Beaker	
90	0.090	0.010
80	0.430	0.010
70	1.300	0.030
60	2.400	0.030
50	3.900	0.100
40	5.200	0.100
30	6.600	0.100
20	7.600	0.100
10	8.200	0.100
0	8.600	0.100

TABLE 4. Data for the small beaker, medium beaker, and large beaker water. The polarization was measured in degrees, and both intensity and intensity error were measured in arbitrary units.

Polarization (degrees)	Intensity (arb. units)	Intensity ± (arb. units)
Small Beaker		
100	0.80	0.03
90	2.25	0.03
80	5.00	0.10
70	8.90	0.10
60	13.00	0.30
50	16.50	0.30
40	21.50	0.30
30	24.00	0.30
20	26.00	0.30
10	25.50	0.30
0	24.00	0.30
Medium Beaker		
90	1.90	0.03
80	3.90	0.10
70	6.20	0.10
60	9.20	0.10
50	11.50	0.30
40	13.50	0.30
30	15.00	0.30
20	15.00	0.30
10	14.50	0.30
0	13.50	0.30
Large Beaker		
90	1.30	0.03
80	2.50	0.03
70	4.00	0.10
60	5.40	0.10
50	6.70	0.10
40	7.60	0.10
30	8.30	0.10
20	8.50	0.10
10	8.10	0.10
0	7.20	0.10

TABLE 5. Data for the small beaker, medium beaker, and large beaker with solution 1. The polarization was measured in degrees, and both intensity and intensity error were measured in arbitrary units.

Polarization (degrees)	Intensity (arb. units)	Intensity ± (arb. units)
Small Beaker		
90	5.00	0.10
80	7.70	0.10
70	11.00	0.30
60	14.00	0.30
50	17.00	0.30
40	18.50	0.30
30	19.00	0.30
20	19.50	0.30
10	17.50	0.30
0	13.50	0.30
Medium Beaker		
90	9.40	0.10
80	13.50	0.30
70	17.50	0.30
60	21.00	0.30
50	23.00	0.30
40	23.50	0.30
30	24.50	0.30
20	22.00	0.30
10	19.50	0.30
0	15.50	0.30
Large Beaker		
90	2.20	0.03
80	3.10	0.10
70	4.30	0.10
60	5.20	0.10
50	5.80	0.10
40	5.90	0.10
30	6.40	0.10
20	5.80	0.10
10	5.10	0.10
0	3.70	0.10

TABLE 6. Data for the small beaker, medium beaker, and large beaker with solution 2. The polarization was measured in degrees, and both intensity and intensity error were measured in arbitrary units.

Polarization (degrees)	Intensity (arb. units)	Intensity ± (arb. units)
	Small Beaker	
90	1.70	0.03
80	5.30	0.10
70	11.00	0.30
60	17.50	0.30
50	26.00	0.30
40	34.00	1.00
30	40.00	1.00
20	44.00	1.00
10	46.00	1.00
0	46.00	1.00
	Medium Beaker	
90	0.58	0.01
80	1.75	0.03
70	3.40	0.10
60	5.80	0.10
50	8.40	0.10
40	11.00	0.30
30	12.00	0.30
20	13.00	0.30
10	13.50	0.30
0	13.50	0.30
	Large Beaker	
90	0.41	0.01
80	1.10	0.03
70	2.25	0.03
60	3.60	0.10
50	5.10	0.10
40	6.40	0.10
30	7.30	0.10
20	8.00	0.10
10	8.20	0.10
0	8.00	0.10

TABLE 7. Data for the small beaker, medium beaker, and large beaker with solution 3. The polarization was measured in degrees, and both intensity and intensity error were measured in arbitrary units.

Polarization (degrees)	Intensity (arb. units)	Intensity ± (arb. units)
	Small Beaker	
90	1.20	0.03
80	3.80	0.10
70	9.20	0.10
60	16.00	0.30
50	24.50	0.30
40	32.00	1.00
30	38.00	1.00
20	43.00	1.00
10	46.00	1.00
0	46.00	1.00
	Medium	
90	0.29	0.01
80	1.05	0.03
70	2.55	0.10
60	4.50	0.10
50	6.60	0.10
40	9.20	0.30
30	11.00	0.30
20	12.00	0.30
10	13.00	0.30
0	13.00	0.30
	Large Beaker	
90	0.15	0.01
80	0.61	0.01
70	1.55	0.03
60	2.80	0.03
50	4.20	0.10
40	5.50	0.10
30	6.60	0.10
20	7.60	0.10
10	8.00	0.10
0	8.20	0.10

TABLE 8. Data for the small beaker, medium beaker, and large beaker with solution 4. The polarization was measured in degrees, and both intensity and intensity error were measured in arbitrary units.

IV. DISCUSSION

Figures 1-6 show the intensity versus polarization with each separate graph respresenting the different solutions. Each of the graphs contain data for different beaker sizes (small, medium, large).

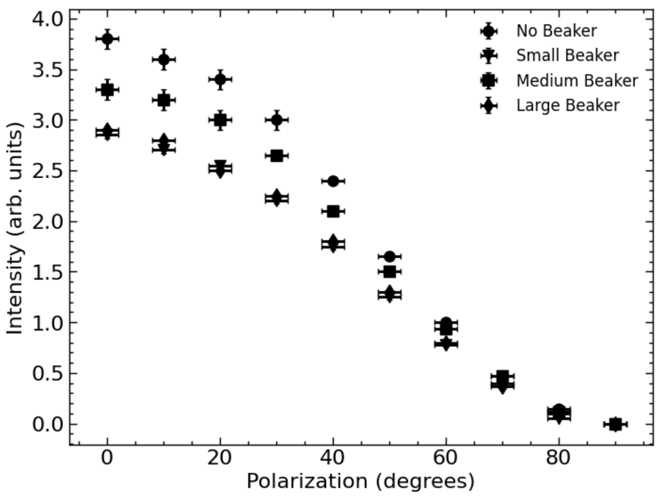

FIG. 1. Intensity vs. Polarization for varying beaker sizes with no water. Here, the polarization is measured in degrees and the intensity is measured in arbitrary units.

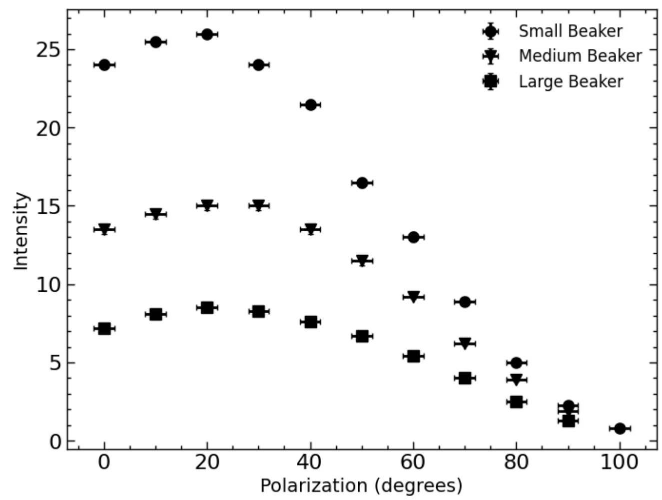

FIG. 3. Intensity vs. Polarization for varying beaker sizes with solution 1. Here, the polarization is measured in degrees and the intensity is measured in arbitrary units.

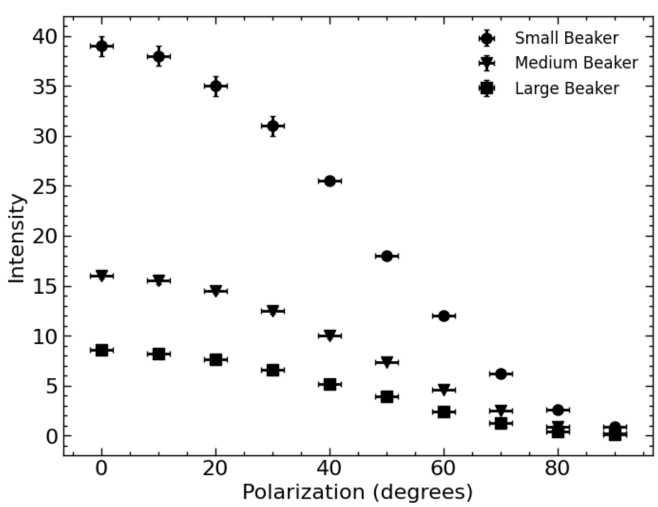

FIG. 2. Intensity vs. Polarization for varying beaker sizes with water. Here, the polarization is measured in degrees and the intensity is measured in arbitrary units.

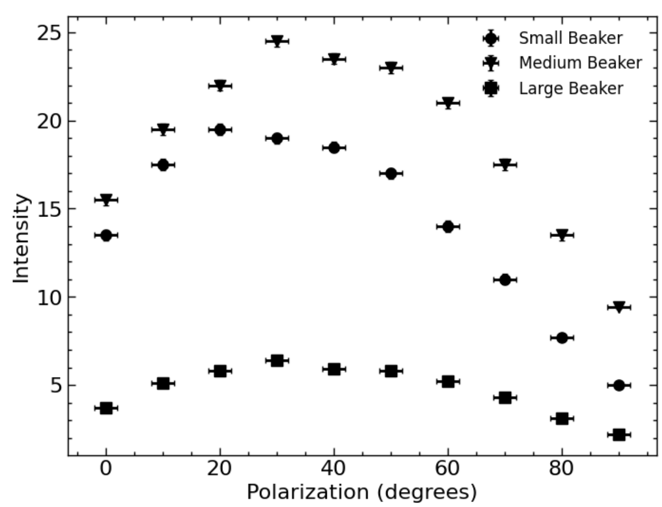

FIG. 4. Intensity vs. Polarization for varying beaker sizes with solution 2. Here, the polarization is measured in degrees and the intensity is measured in arbitrary units.

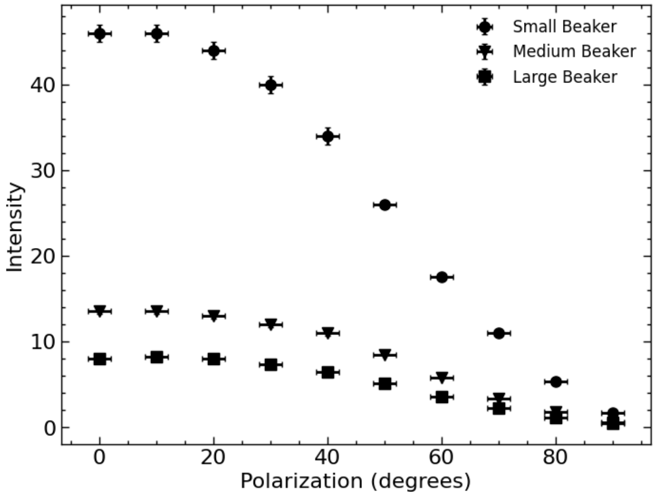

FIG. 5. Intensity vs. Polarization for varying beaker sizes with solution 3. Here, the polarization is measured in degrees and the intensity is measured in arbitrary units.

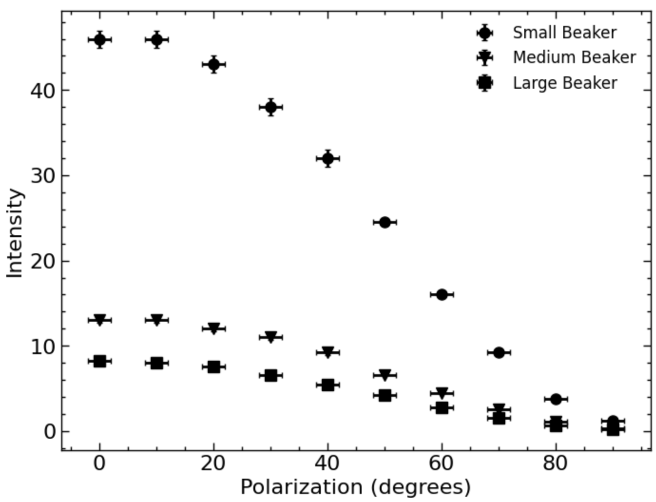

FIG. 6. Intensity vs. Polarization for varying beaker sizes with solution 4. Here, the polarization is measured in degrees and the intensity is measured in arbitrary units.

Each of the following graphs show the phase shift as a function of sugar concentration in water, with each separate graph containing data from one beaker size. The phase shifts were found by fitting the intensity vs. polarization data to a cosine function in the form $A\cos(Bx + C) + D$. We invoked the ODR (orthogonal distance regression) class from the SciPy Python package to fit these data sets to the previously mentioned cosine function. By representing phase shift versus sugar concentration, we can quantify how the polarization of light changes as a function of sugar concentration in water.

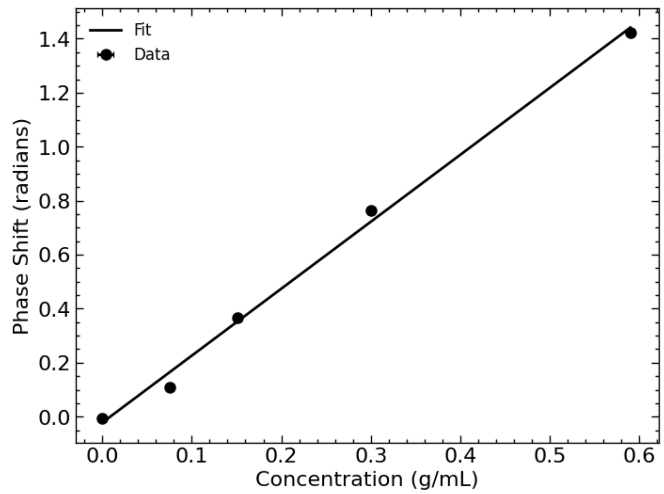

FIG. 7. This graph shows the phase shifts for the large beaker.

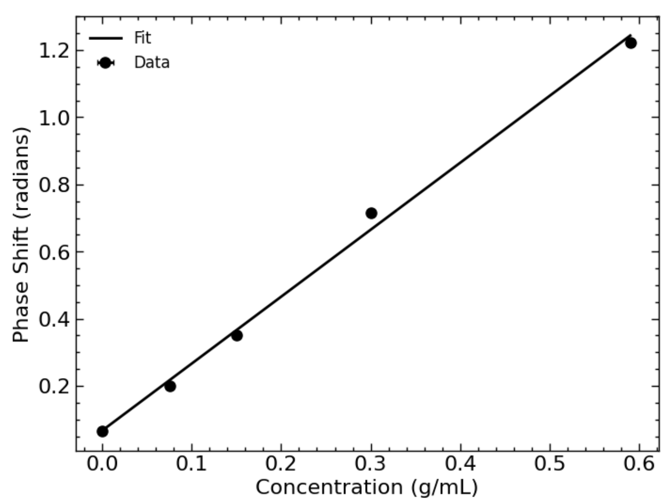

FIG. 8. Phase shifts for medium beaker.

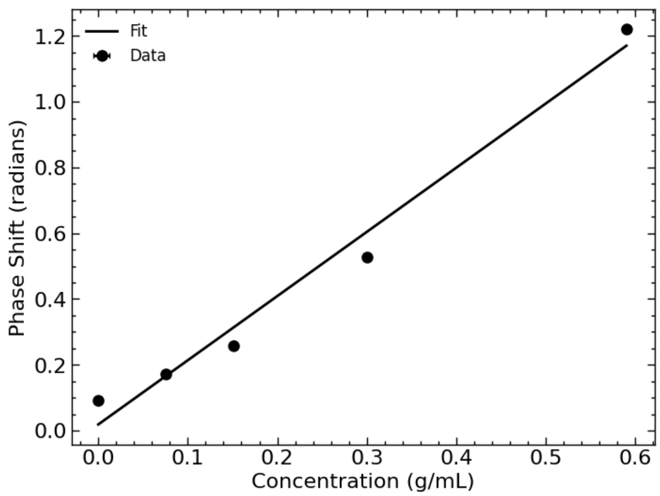

FIG. 9. Phase shifts for small beaker.

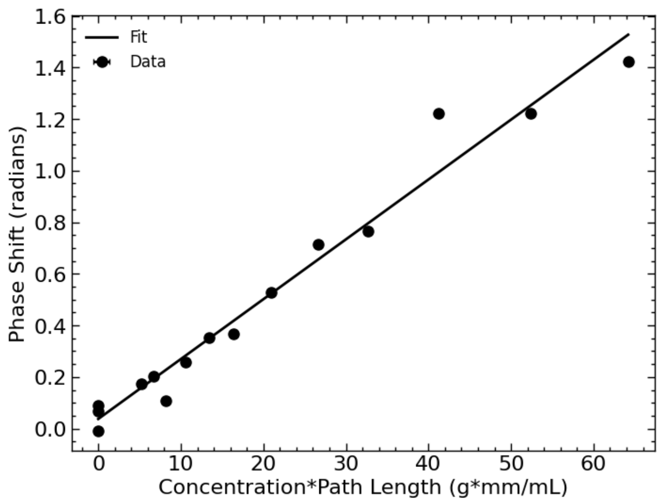

FIG. 10. This figure encapsulates the phase shift in radians as a function of both concentration in grams per milileter and the path length in milimeters, where the horizontal axis is the product of the concentration and path length values.

V. CONCLUSION