Self-Made Device to Measure Optical Density of Solutions

- Andrew Tsui

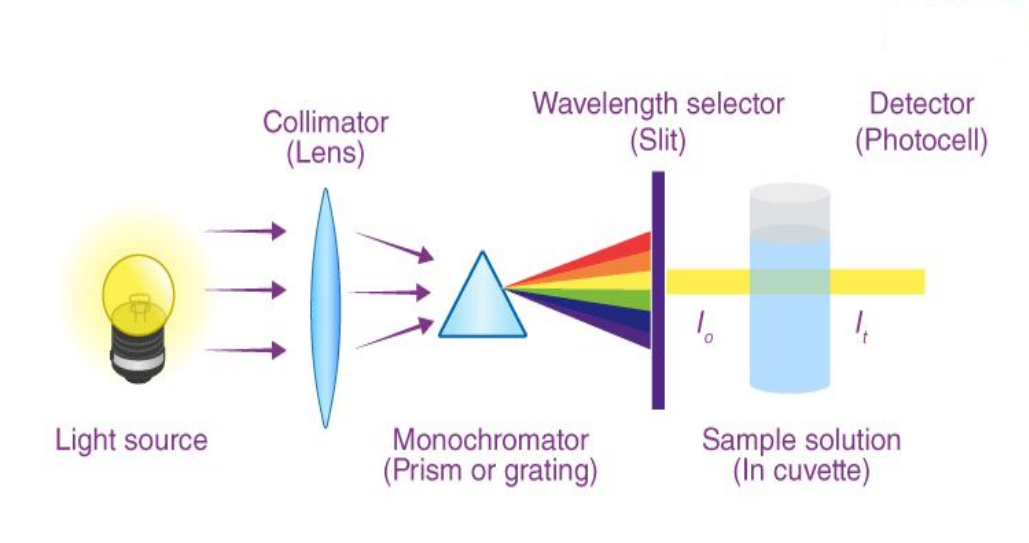
Wyoming Seminary College Preparatory School

Rationale of My Design

- I had a lot of fun when I play and compete in all kinds of Lego EV3 Robotics Tournaments and gradually arouse my interest in **Electric Engineering.**
- **Spectrometer with LabQuest** was a tool I used frequently in the past, then I was attempting to create a simple device that may achieve the same goal.
- The process helped me learned a lot in both **hard/software** and gain knowledge about the **optical knowledge** laid behind data.

The Concept of Optical Density

Optical density (OD): is a measure of how much light is absorbed or scattered by a solution.

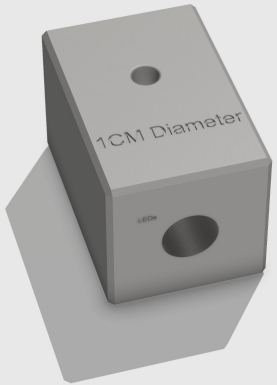


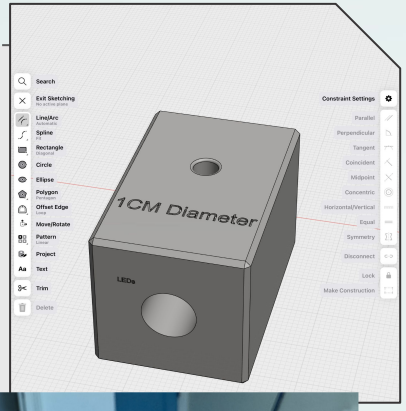
Objective of My design:

- Use of simple, accessible materials
- Mimic the function of Spectrometer
- Easy to build and conduct experiment
- Explain and learn from the experimental testing result
- What may be improve or fixed?

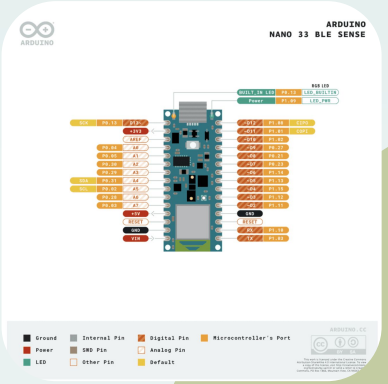
Material List

1. Customized Acrylic Block





2. Microprocessor- Arduino Nano 33 BLE



3. Photodiode- BPW21R (Max565nm / 100°)

VISHAY
www.vishay.com

BPW21R
Vishay Semiconductors

Silicon Photodiode

FEATURES
- Package type: leaded
- Package form: TO-5
- Dimensions (in mm): Ø 8.13
- Radiant sensitive area (in mm²): 7.5
- High photo sensitivity
- Adapted to human eye responsivity
- Angle of half sensitivity: φ = ± 50°
- Hermetically sealed package
- Cathode connected to package
- Flat glass window
- Low dark current
- High shunt resistance
- High linearity
- Compliant to RoHS Directive 2002/95/EC and in accordance with WEEE 2002/96/EC

RoHS COMPLIANT

DESCRIPTION

BPW21R is a planar Silicon PN photodiode in a hermetically sealed short TO-5 case, especially designed for high precision linear applications.

Due to its extremely high dark resistance, the short circuit photocurrent is linear over seven decades of illumination level.

On the other hand, there is a strictly logarithmic correlation between open circuit voltage and illumination over the same range.

The device is equipped with a flat glass window with built in color correction filter, giving an approximation to the spectral response of the human eye.

APPLICATIONS
- Sensor in exposure and color measuring purposes

Experimental Setup

Light Sources: 10mm LEDs of different colors

Red (620–630 nm)

Orange (600–605 nm)

Yellow (588–595 nm)

Green (520–525 nm)

Blue (460–465 nm)

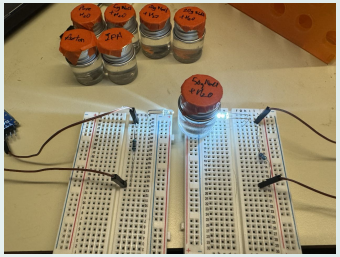
01

02

03

Solutions Tested:

1. Pure Water (Baseline)
2. 15% Saline Solution (NaCl)
3. Ethanol
4. Acetone



Sample Holder: Customized Acrylic Block

Microcontroller: Arduino Nano 33 BLE

Photodiode: BPW21R (565 nm)

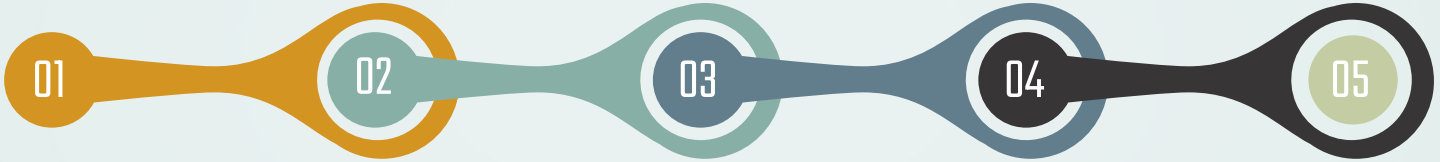
Procedure of Making it

Assemble it up

Make sure the circuits and signal pinouts are correctly connected. Check for signal fluctuation

Sample Testing

Switch the Pure Water with other test solutions.



Preparation

Obtain all the dupont wires and mini-board, and solution container (cuvette would dworks)

Calibration Step

Utilize Pure Water to create a baseline value for later data comparison.

Data Analysis

Compare the data and analyze the potential reasoning behind the patterns shown

Hypothesis

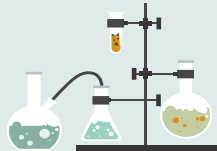
Different substances will exhibit varying absorbance and scattering properties.

Pure liquids (water, ethanol, acetone) affect light transmission primarily through absorption.

Shorter wavelengths (blue, green) experience more scattering, while longer wavelengths (yellow, orange, red) are less affected.

Control Variables:

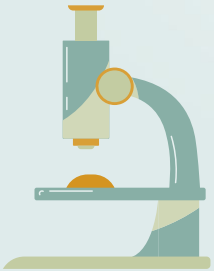
1. The matt surface on acrylic block due to CNC process
2. Minor noise and signal disturbance on data
3. Potential light sca



Data Analysis (Pure Water/Baseline)

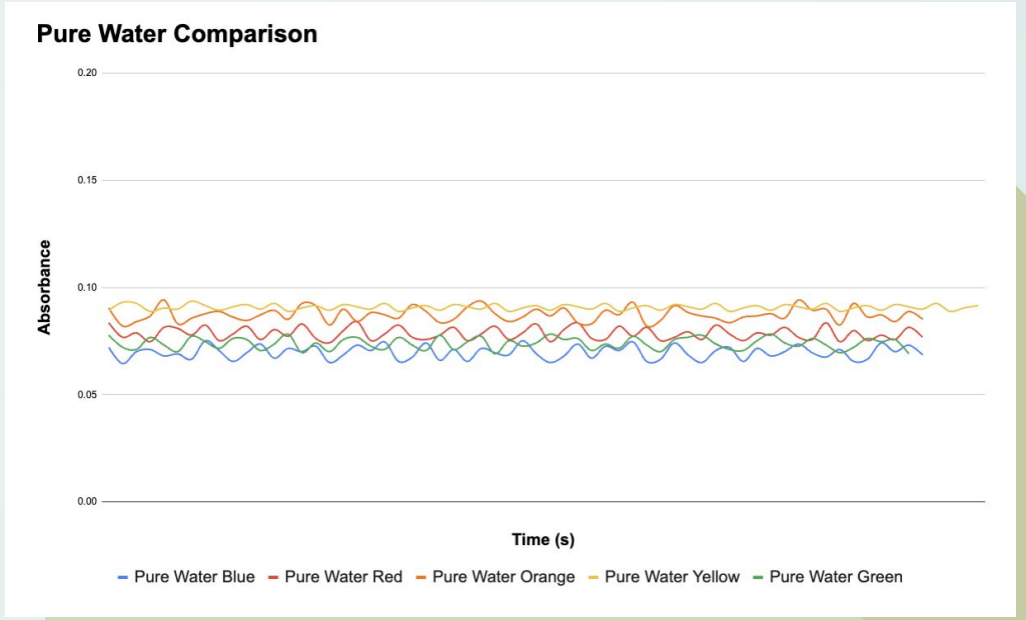
- Average value of absorbance hover around the range of 80-85, but it shows a distinct pattern how pure water react to different colors of LED.

- Based upon water's nature of its molecular vibrations and electronic transitions, the absorbance suppose to go from low-high (blue→green→yellow→orange→red).



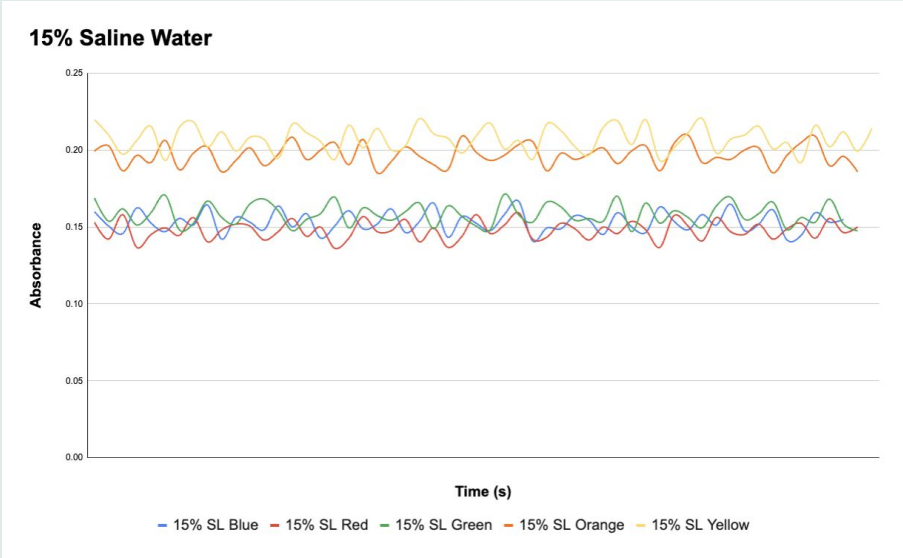
Test Condition (Ta=25°C, IF=20mA)

	Color	Wavelength (nm)	Light Intensity (mcd)	Angel
	Red	620-630nm	2000-3000	120°
	Blue	460-465nm	4000-5000	120°
	Green	520-525nm	14000-16000	120°
	Yellow	588-595nm	2000-3000	120°
	Orange	600-605nm	2000-3000	120°



- **Average value from 4 trials**

Data Analysis (15% Saline Water)



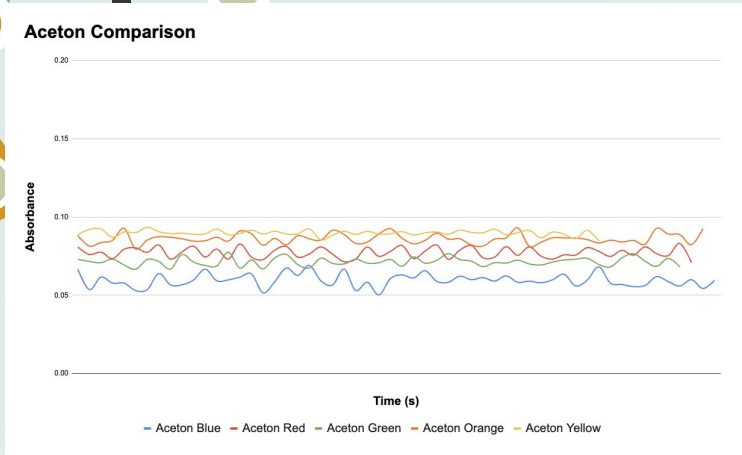
- The absorbance values for 15% saline water are generally lower across all wavelengths compared to pure water.

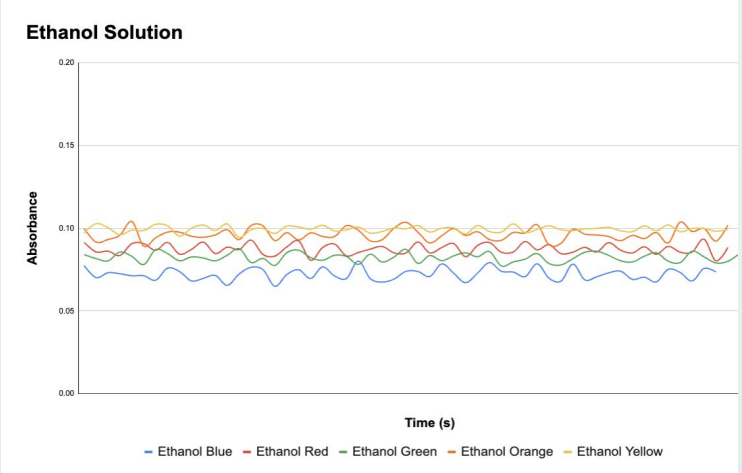
- **Effect of Ions in Saline Solution (Na^+, Cl^-)**
- The presence of dissolved ions increases the overall refractive index of the solution.

- This reduces water's ability to absorb certain wavelengths, leading to slightly higher transmission (lower absorbance).

- **Average value from 4 trials**

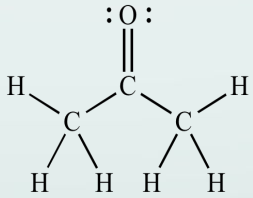
Data Analysis (Acetone/Ethanol)



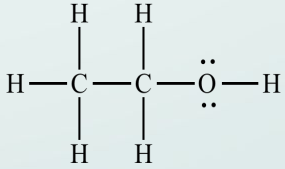


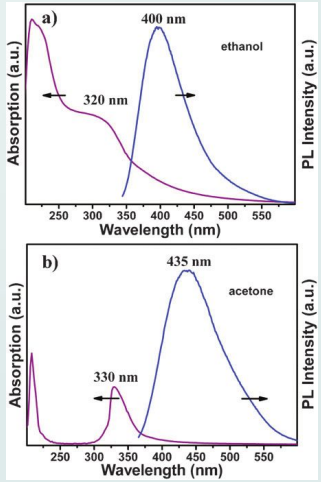
- Ethanol and Acetone exhibit higher average absorbance values compared to pure water.
- They both have about the same average absorbance value, which is reasonable for their similar refractive index.
- The molecular and electronic structure affects light transmission by creating different polarity and

Aceton:
1.358

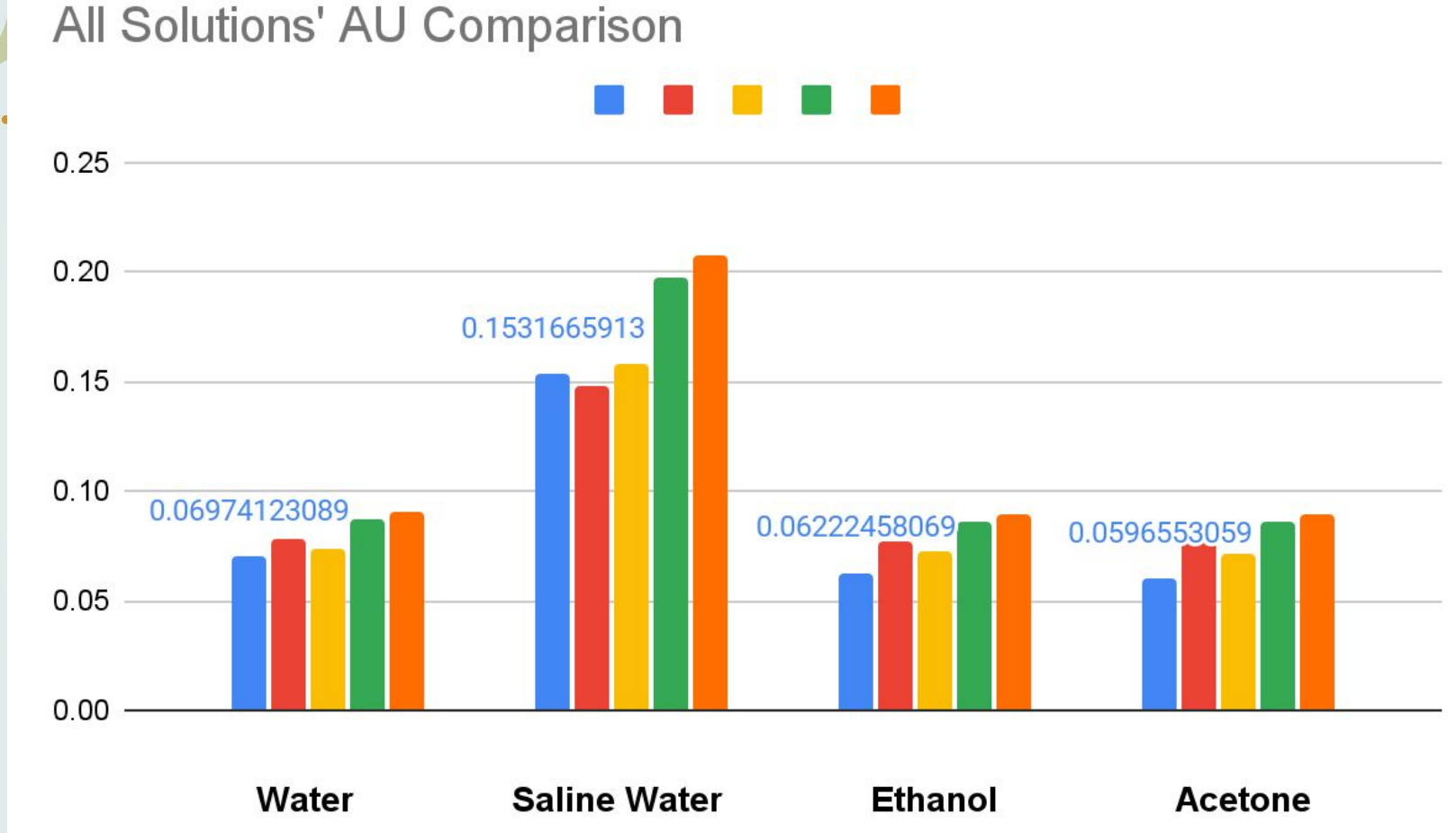


Ethanol:
1.361





- **Average value from 4 trials**


All Solutions' AU Comparison
0.25
0.20
0.15
0.10
0.05
0.00
0.06974123089
0.1531665913
0.06222458069
0.0596553059
Water
Saline Water
Ethanol
Acetone

Data Comparison

	Pure Water	Saline Water	Ethanol	Acetone
Average AU	0.08	0.17	0.078	0.075
Standard Error	0.03%	0.1%	0.04%	0.04%

Conclusion

My device did achieve my hypothesis and shows the difference optical density among solutions. However, there are some minor flaws that affect the accuracy. Overall, it’s a mimicable and interesting device that can be made easily and understand the concept behind making it.

References

- Donnelly, K. (2006, March 2). Introduction to the spectrophotometer. Kevin Donnelly. https://faculty.umb.edu/yvonne_vaillancourt/Bio210/labs/appendix%203%20%20sample%20lab%20report.pdf
- O'Toole, M. (2008, April 7). Absorbance based light emitting diode optical sensors and sensing devices. Martina O'Toole and Dermot Diamond. https://www.mdpi.com/1424-8220/8/4/2453
- Spectrophotometer on-the-go: The development of a 2-in-1 uV–Vis portable arduino-based spectrophotometer author links open overlay panel (J.-J. Poh, Comp.). (2021, July 1). https://www.sciencedirect.com/science/article/abs/pii/S0924424721001618