ISSN (Print) : 2337-9030 ISSN (Online) : 2685-2608
PILLAR OF PHYSICS
JURNAL BERKALA ILMIAH FISIKA
Vol. 18 (2), 2025, page. 96-108
DOI : https://doi.org/10.24036/w9crvk35

A PORTABLE SPECTROPHOTOMETER WITH A VISIBLE LIGHT AS RADIATION SOURCE FOR ACID-BASE CONCENTRATION MEASUREMENTS

Mona Berlian Sari[1*], Widya Anisa[1], Anggun Sisri Matondang[1], Muhammad Akbar Andi Arif[2]

[1] *Department of Physics, Universitas Negeri Padang, Jl. Prof. Dr. Hamka Air Tawar Padang 25131, Indonesia*
[2] *Department of Smart Agricultural System, Chungnam National University, Daejeon 34134, South Korea*

Corresponding author. Email: monaberliansari@fmipa.unp.ac.id

ABSTRACT

Acidity concentration measurement is a rigorous step throughout the entire quality control of food products that must be evaluated using a strictly recognized and standardized method. One method that can be used to measure concentrations efficiently is a spectrophotometer. In this work, we developed a spectrophotometer using a photodiode sensor to measure Acid-Base concentration so-called spectABC. The spectABC has high performance and sensitivity, is cost-effective, easy to build, and easy to use. The acidic coffee powder and alkalinity of $NaHCo_3$ are measured as the sample in this work. The spectABC shows good performance in measurement transmittance, absorbance, and concentration of the sample. The relative error percentage of the measurement is reported to be less than 4.8% in the measurement of the coffee solution. The average percentage of accuracy is found to be 98.92%. In the measurement of $NaHCo_3$ concentration, the measurement error percentage is less than 4.46%. The average percentage of accuracy is found to be 97.67%. Overall measurements have consistently high accuracy which is above 97%. Detail about the work is described in this paper.

Keywords : Acid-base, Concentration, Radiation, Sensor, Spectrophotometer

I. INTRODUCTION

Acidity is a crucial characteristic of many foods and beverages due to their correlation with nutritional value and sensory quality of foods [1]. Acidity can be generated naturally from the ingredient of the food or developed during production processes such as fermentation, preservation, and packaging [2, 3]. In the food production industry, acidity measurement is an essential protocol to verify that the products meet regulatory criteria, such as posing no risks to the customer's safety and health. In addition, an acidity test is conducted to ensure and control the product standards of quality [4, 5], determine acidic concentration for customers [6], satisfy nutritional value, determine rigorous temperature-control criteria especially for storage shelves [6, 7], prohibit the ability of a microorganism growing in a specific food [7, 8, 9], and provide specified characteristics such as texture, taste, appearance, and expire date [6, 7, 10]. Therefore, acidity testing is a rigorous step throughout the entire food processing that must be intensively conducted. Majority of foods and beverages that are preserved by acidity must be evaluated using a strict recognized and standardized method.

Several techniques and tools are used to analyze the pH level of acidic and basic solutions such as using litmus paper [11], universal pH indicator solutions [12], pH meters [13], and titrations [14, 15]. Titratable acidity and pH are two interconnected concepts correlated to the acidity. Titratable acidity, so-called total acidity, measure total acid concentration of a food [16].The pH measures acidity in terms of H+ ions existence in the sample, so-called active acidity. The use of litmus paper is less-effective because the sensitivity is poor [17]. It shows that the pH value read by litmus paper is approximate value by determining the closest color resemblance between the

Submitted: 27-09-2025 Accepted: 30-10-2025 Published: 31-10-2025

litmus paper and the color chart. The pH meter is better than litmus paper. However, the concentration or molarity of solutions is not provided in pH meters or measurement using litmus paper. To determine the characteristics of acids and bases, a pH meter is not sufficient and must be accompanied by a titrator. Titration is the most common method to determine the concentration of an unknown solution by dropping an indicator solution of known concentration into the solution. Although titration is a well-established sample preparation method for a long time, determining the concentration or molarity value of an unknown solution requires manual data processing. One method that can be used to measure concentrations efficiently is a spectrophotometer.

Spectrophotometer works based on the interaction of light with matter. When electromagnetic light interacted with the mater, the light can be transmitted, scattered, absorbed, reflected, or fluorescence [18]. By comparing the intensity before and after passing through the matter, the amount of absorption, transmittance, and concentration of matter could be determined. Sophisticated apparatus spectrophotometers need lots of production and maintenance costs, well-trained operators [19], the quality of the analysis depends on the price and complexity of the optical system [20], and cannot be used over time such as for real-time monitoring measurements. In addition to that, the demand of portable and cost-effective spectrophotometers is high especially for the laboratory with low budget and space or when the unstable measure parameters must be determined quickly on-site [21].

To overcome this problem, several inexpensive spectrophotometer is created with different detectors, light source and method. One of which is low-cost LED spectrophotometer for activity analysis of iron in water [22] with total cost only 9 USD. This spectrophotometer consists of LED, cuvette sample and 2 pcs battery supply. However, the performance is very basic with low sensitivity. The measurement result display in laboratory voltmeter, therefore only voltage value can be obtained. In addition to that, output voltage should be manually analyzed if we need concentration value. Other kinds of detector that can be used is smartphone camera such as 3D-Printable smartphone spectrophotometer [23] and digital image colorimetric detector for batch and flow-based acid-base titration [24]. Smartphone camera-based spectrophotometer is more affordable than conventional spectrophotometer. However, it is suffer in data analysis because it depends on image selection and pixel position quality of camera, spectrum should be compared to the reference, and requires additional analysis software for measurement data analysis. In addition to that, the camera sensor is difficult to be calibrated. Therefore, the percentage of error have high slope compared to the standard spectrometer, which is reported to be around 30% [22, 24].

Other low-cost spectrophotometer is developed using light dependent resistor as sensor [25], however it is hard to accurately measure the sample absorbance. In addition, sensor characteristics is suffer in linearity so it could not effectively measure intensity, especially for analytical high precision instruments. Other portable spectrophotometer Arduino based have been developed such as with White LED as a light source for analyzing solution concentration [20, 26], a low-cost UV-Vis spectrophotometer for the detection of mercuric ions assisted by chemo sensors [27], a 2-in-1 UV-Vis portable Arduino-based spectrophotometer [28, 29], and a portable low-cost Arduino-based photo-and fluorimeter [21]. However, those developed spectrophotometer suffer in stabilization of data results [21], low precision (especially in low concentration) [27], low sensitivity in certain wavelength [27], and high error percentage in some measurements [21]. Therefore, spectrophotometer systems have various drawbacks that have gaps and the potential to continue to be developed with various features aimed at increasing precision, accuracy, flexibility, and other overall performance. To stabilize the data results, all background noise, sensor calibration, including sample preparation should be treated correctly [30, 31]. Therefore, it will affect to the increasing of precision, accuracy and sensitivity of system. In this paper, we developed digital visible spectrophotometer so called SpectABC (Spectrophotometer Acid-Base Concentration) for measurement of acid-base concentration. SpectABC is a portable spectrophotometer, easy to configure, Details are described in this paper.

II. METHOD

The electronic circuit of SpectABC is shown in Fig. 1. According to Fig. 1, Arduino Uno R3 is used as a microcontroller to control all the input and output processes. SpectABC uses LED bright white as a light source, the intensity of the light is regulated by a resistor which is connected in series to the LED light source. The sensitivity of light is sensed by the Photodiode sensor. To stabilize sensor output voltage, zener diode and capacitor are paralelly embedded to the output sensor circuit. Output voltage supply is regulated with IC regulator 7805 to obtain stabilized 5 volt input voltage for microcontroller. Arduino R3 output is connected to LCD screen for data display. All the electronic circuits are placed in black box.

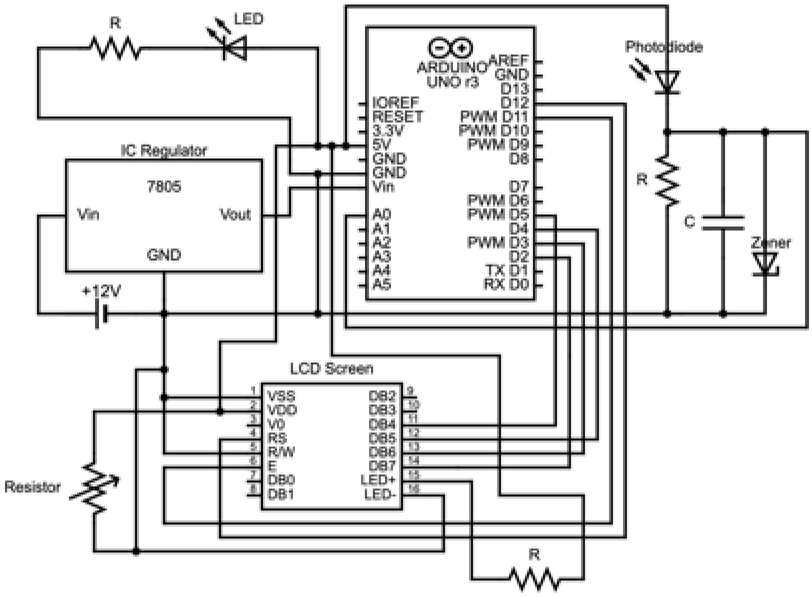


Fig. 1. Electronic Circuit of SpectABC

In this research, the samples that are used are arabica coffee and bicarbonate of soda ($NaHCo_3$) powder. The light source and sensor are placed opposite each other. In between, dissolved sample solution is placed in transparent cuvette sample. When the SpectABC is activated, the light source will hit the sample and the sensor will measure the transmitted of light passed through the sample. This intensity is compared to the intensity of light source before hit the sample as reference. When the radiation of light interact with the material, some of radiation energy is transferred to the materials electron. Materials physical properties such as density, molar, and volume [32] have an influence to the amount of transmitted and absorption energy produced [18]. According to the Lambert-Beer law, "if a monochromatic light passes through a transparent material, the intensity of the transmitted light is proportional to the thickness and the density of the material" [19]. The absorbance value depends on the light source wavelength. Therefore, the absorbance value is not measured directly but must be calculated using the ratio of some of the light transmitted intensity through the sample [33]. If I is the light intensity after passing through the sample and I_0 is the intensity of light source [34], the transmitted light intensity fraction (T) can be formulated as equation 1 below.

$$T = \frac{I}{I_0} and\ A = log_{10}\left(\frac{1}{T}\right) \quad (1)$$

Figure 2 shows the programming flowchart of Arduino microcontroller device to read the sensor data and display the measurements results. There are three main step conducted in the spectABC microcontroller programming [35]. First, reading sensor output voltage that is changed based on the amount of light attached to the sensor surface. Second, sensor output voltage is converted to the intensity value using the equation which is obtained in the sensor characterization process. Third, the intensity value is converted to the concentration value using the equation obtained during calibration process. All data collected send to the display so the value of absorbance, transmittance and concentration of the sample could be obtained.

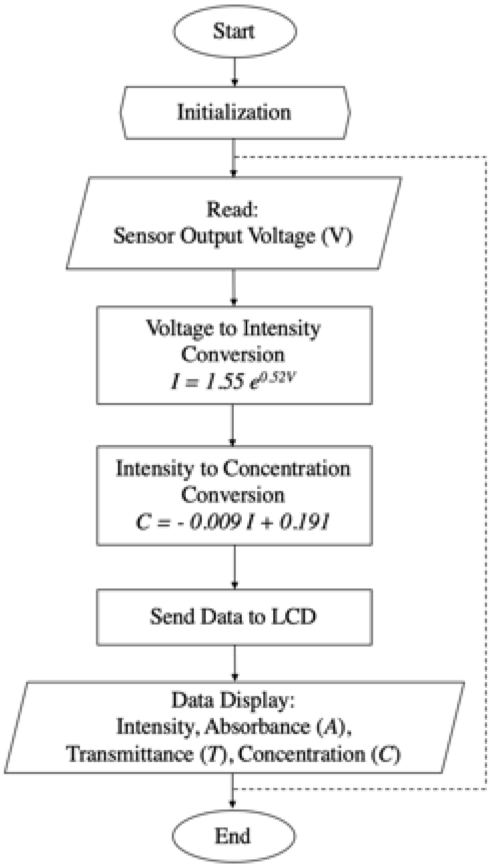
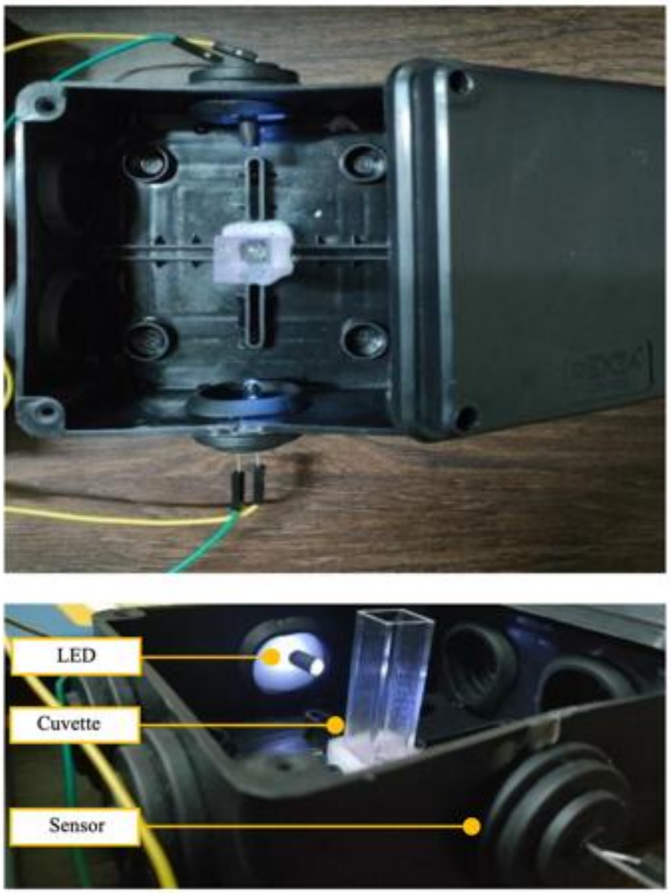


Fig. 2. Programming flowchart of Arduino Uno Microcontroller

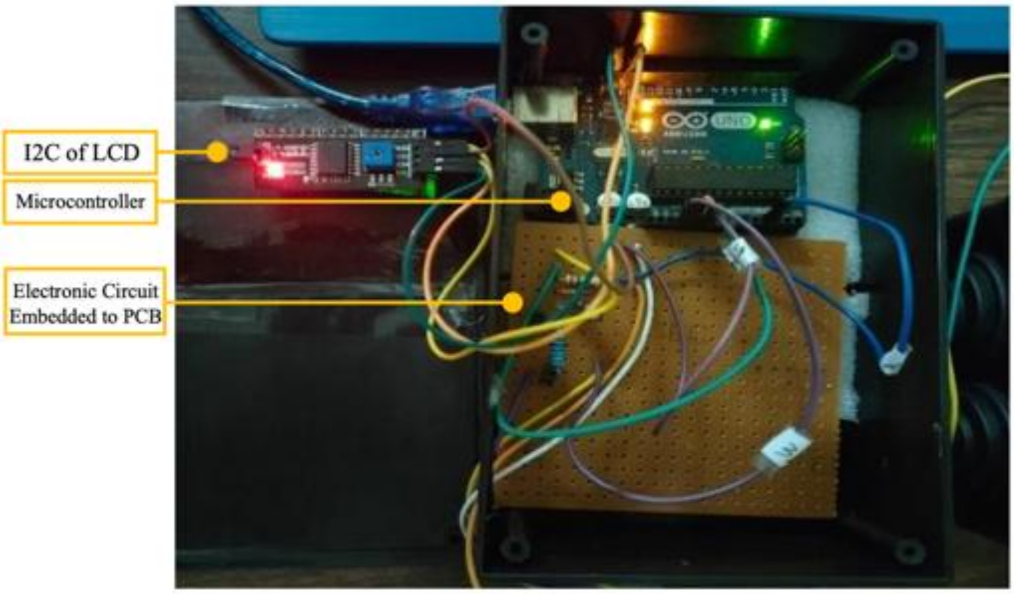
III. RESULTS AND DISCUSSION

3.1. SpectABC system

The spectABC system consists of two black compartments for efficiency. Therefore, the developed spectABC system is suitable for various measurement site, both laboratory and in situ. The first box is used for photodiode sensor, LED as light source, and cuvette sample in between as shown in Fig. 3 (a). Polystyrene cuvette is used for sample placement that have 10 mm light path. This cuvette can accommodate 2.5 to 4.5 ml solutions. Wavelength operating range of the cuvette is 340 – 900 nm. Cuvette sample is placed between LED light source and photodiode sensor. The distance between sensor-cuvette and cuvette-light source is 5.5 cm. Sensor, LED light source, and cuvette are placed in black box to block the background noise from environment. The second compartment is used to put all the electronic circuit as well as microcontroller as shown in Fig. 3 (b). LCD screen for data display is embedded at the lid of the second compartment.



(a)



(b)

Fig. 3. Hardware system and electronic circuit of SpectABC

3.2. Sensor Characteristics

A photodiode sensor is used to detect the LED source's visible light. The output voltage of the photodiode changes depending on the amount of light intensity attached to them. Sensor characteristic is observed by measuring the sensor output voltage in the variation of intensity. Here, the light intensity is measured by a Light meter and varies by rotating the varying resistance of the potentiometer which is connected to the LED source. LED are widely used as visible light electromagnetic spectrum light source in analytical instrumentation application [25]. The intensity is vary from 2 Lux to 195 Lux by varying variable resistor which is connected in series with the LED. We apply exponential fit to the data obtain to find regression coefficient and correlation formula between sensor output with the intensity of light. The regression coefficient obtained from exponential fit (red line) of the data distribution shown in Fig. 4 is 0.98. The correlation formula between sensor output with the intensity of light is stated in the Equation (2).

$$I = 1{,}55\ e^{0{,}52V} \tag{2}$$

where I is the intensity of light attached to the sensor surface, and V is the sensor output voltage. The sensor output is changed exponentially by increasing of the light intensity as shown in Fig. 4. Increasing light intensity affects to the increasing of sensor output voltage. By using Equation 2, the sensor output voltage is converted to the intensity value in microcontroller code.

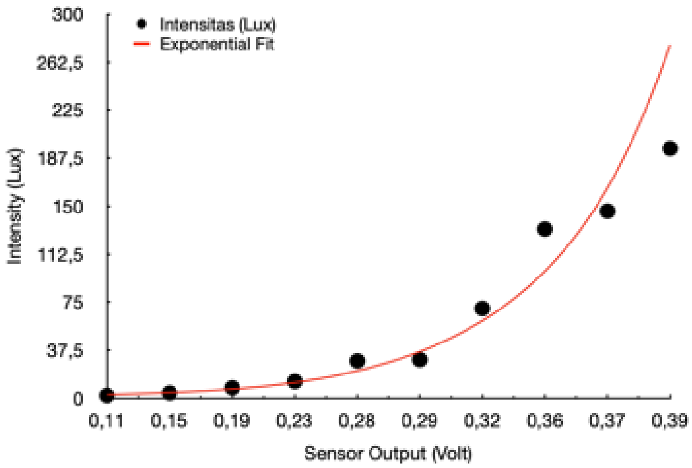


Fig. 4. Graph of changes in the value of light intensity as a function of changes in the value of sensor output voltage

3.3. Validation Test

A validation test conduct to validate the results and obtain technical specifications of the developed system such as precision and accuracy. Accuracy is measured by comparing the developed tool to the standard tools, simulation, theoretical known results, or calculated prediction in the same condition. To validate the technical performance of the digitally developed system, measuring accuracy was mandatory to do. After converting the sensor output voltage to the intensity value using Equation 2 as discussed previously, the light intensity value measured by the photodiode sensor (dotted black) is then compared to the intensity value measured by the standard tool which is the light meter (red square) as shown in Figure 5. It is found that both results give consistently similar number resulting low relative error percentage which is less than 5% as shown in the bottom side of Figure 5. The intensity of light varies between 9 to the 580 Lux. Details comparison of light intensity measured by the photodiode sensor and standard light meter could be seen in Figure 5. The bottom side plot in Figure 5 shows the relative error percentage of the measurement which is found to be less than 5% with an average of around 2.83%. Based on the Figure 5, the accuracy of spectABC in measuring light intensity is reported to be 97,17% on average.

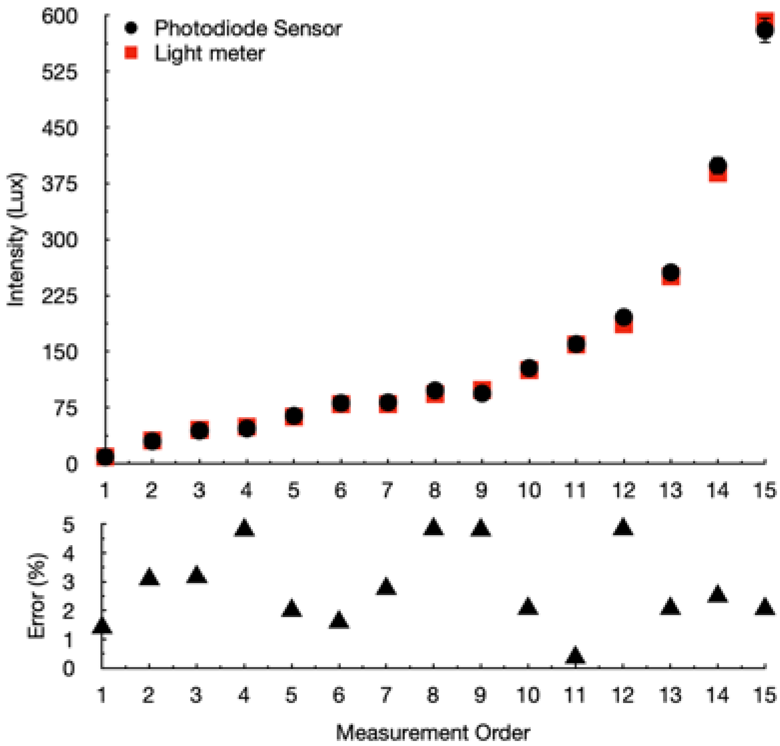


Fig. 5. The measurement results of light intensity measured by SpectABC (photodiode sensor, dotted black) compared to the standard light meter (red square) and the percentage of measurement error by comparing both results

The precision measurement of developed SpectABC was conducted by 10 times repeated data taking at the intensity of 80 lux. In this measurement, we must strictly ensure the conditions are the same in each repetition. The measurement of precision is needed to obtain an information of the data stabilization in each repetition. Consistent results are obtained as shown in Figure 6. According to the Figure 6, data distribution and error bar of the intensity measure by the photodiode sensor embedded in SpectABC (black dotted line) are overlapped with the intensity measure by a light meter (red dashed line) resulting in 99,17% precision.

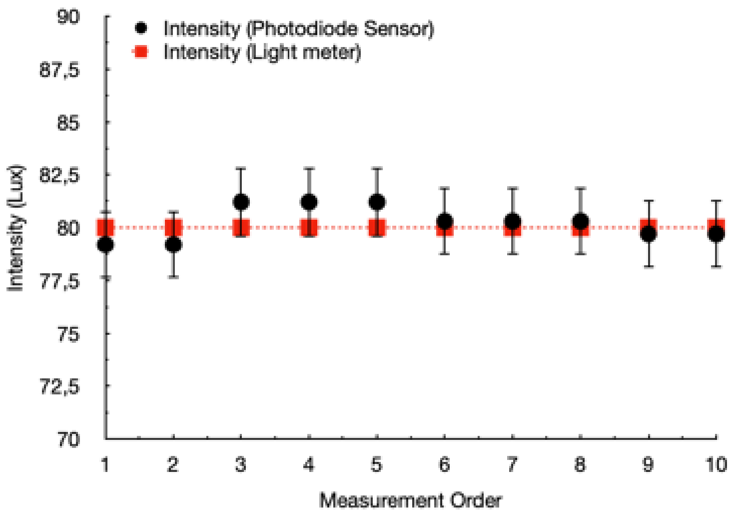


Fig. 6. Measurement of light intensity by SpectABC (dotted black) with 10 times repeated measurement at the same condition and the comparison between standard light meter (red square dashed line)

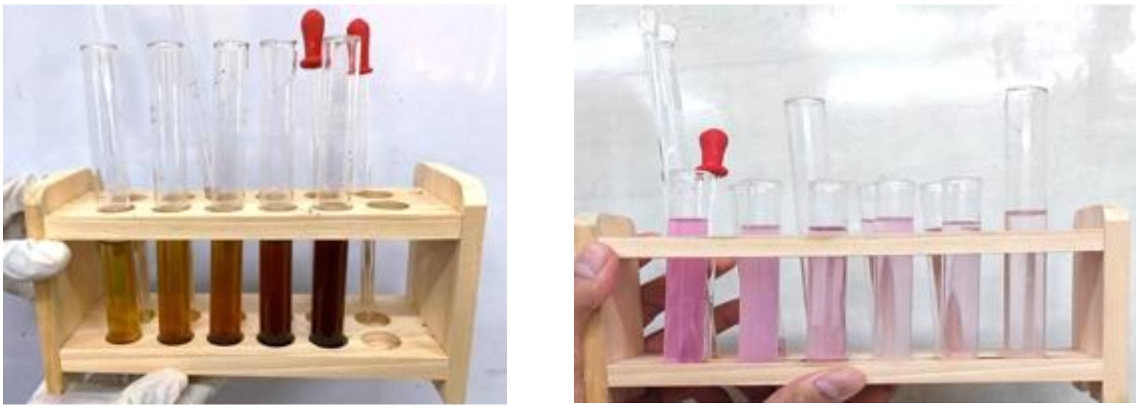
3.4. Measurement of Concentration

Sample Preparation. The samples that are used in this research are arabica coffee and bicarbonate of soda ($NaHCo_3$) powder. Sample is prepared by dissolved the coffee and bicarbonate of soda powder in 10 ml distilled water. Samples powder were weighed using an analytical balance to measure the mass accurately. To obtain various concentration of samples, the mass of sample are vary as shown in the Table 1. Samples are titrated by pH indicator of 10 drops phenolphthalein ($C_{20}H_{14}O_4$) and 4 drops methyl red ($C_{15}H_{15}N_3O_2$) respectively. Methyl red and phenolphthalein are common synthetic and organic chemical compound indicator dye respectively to determine pH transitions. By varying the concentration of each sample, we obtained colour transitions as shown in Figure 7.

Table 1. Mass (g) and concentration (g/mL) variations of samples

No	Mass (g)		Concentration (g/mL)	
	Coffee	Natrium Bicarbonate	Coffee	Natrium Bicarbonate
1	0.101	0.198	0.010	0.020
2	0.201	0.292	0.020	0.029
3	0.303	0.314	0.030	0.031
4	0.401	0.417	0.040	0.042
5	0.501	0.621	0.050	0.062
6	0.604	0.914	0.060	0.091
7	0.714	1.130	0.072	0.113
8	0.801	1.529	0.080	0.153
9	0.903	1.830	0.090	0.183
10	1.050	2.199	0.105	0.220

Methyl red turns red in acidic solutions which pH value below 4.4, attains yellow in pH value over 6.2, and attains deep orange in between 4.4 and 6.2 pH value. Methyl red is most effective between pH value specific range of 4.4 and 6.2. Most of coffee varieties are acidic, with an average pH value of 4.58 to 5.10. Therefore, methyl red is used as indicator pH transitions for the coffee solutions. Phenolphthalein is colorless in pH value below 8.5 and turns a magenta to deep red hue above pH value of 9.0. Phenolphthalein is most effective between pH value range of 8.2 and 10.0 such as bicarbonate of soda which is have pH value lies between 8 to 9. Therefore, phenolphthalein used as indicator pH transitions for the bicarbonate of soda solutions. Amount of sample is placed in spectrophotometer cuvette to obtain desired data information of the sample solution.



(a) (b)

Fig. 7. Various concentration of (a) arabica coffee solutions with 4 drops of methyl red indicator and (b) bicarbonate of soda solutions with 10 drops of phenolphthalein indicator.

3.5. Sensor Calibration

The sensor is calibrated by measuring the intensity of light that passed through the sample by varying the concentration of the sample. The sample that is used for the calibration is bicarbonate of soda ($NaHCo_3$) solution. Samples vary from 0.011 grams/mL to 0.184 grams/mL. The sample is placed in a cuvette between the LED light source and the photodiode sensor. Then, the sample is characterized for about 2-5 minutes for each and the value of concentration is observed. Intensities of light after passing through the sample are reported in Figure 8.

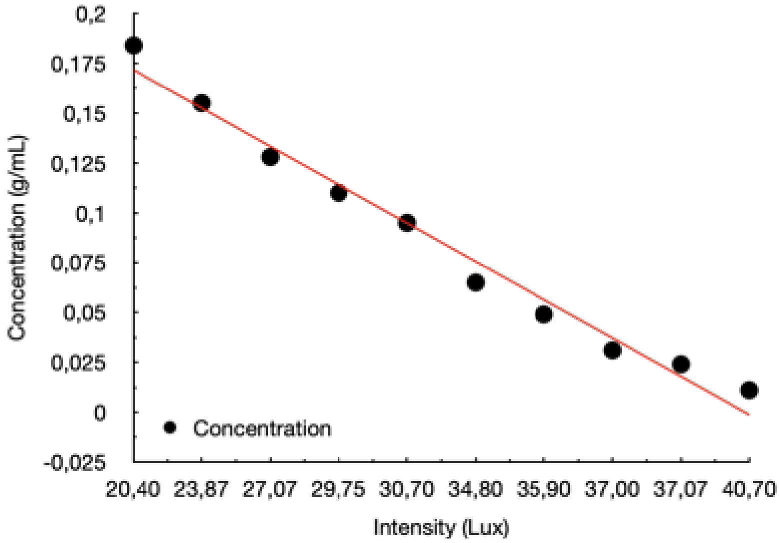


Fig. 8. Graph of changes in intensity of light (Lux)
by various sample concentration (g/mL) measured by spectABC

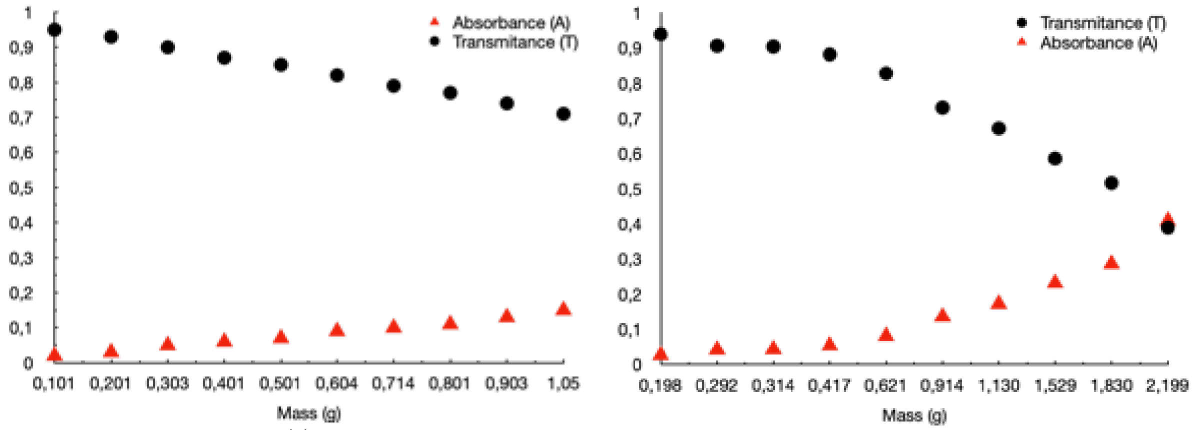
According to Figure 8, it shows that the intensity is inversely proportional to the concentration. Increasing concentration affects the decrease of light intensity transmitted. This phenomenon is consistent with the Lambert-Beer law. The radiation energy from initial light interacts with the atomic particle of the sample [19]. Increasing the concentration of the sample have the same meaning as increasing the amount of atomic particle in the sample. A number of atomic particles in the sample affect the amount of light particle absorbed and transmitted. We applied linear fit in data distribution in Figure 8, the correlation between concentration and light intensity after passing through the sample is described by Equation (3):

$$C = -0.019\,I + 0.191 \tag{3}$$

where C is the concentration in grams/mL and I is the intensity in Lux. The regression coefficient obtained from the linear fitting is 0.98. The regression coefficient obtained from fitting are close to 1, meaning that the measurement result is not quite far from the true value. The Equation 3 is used in the programming code to convert the value of intensity sensed by photodiode sensor to the concentration. It can be used for variable sample in acidity-alkalinity range.

3.6. Measurement of Transmission and Absorption

Transmittance (T) is the ratio between the initial light (reference) intensity to the intensity of light transmitted by the sample. When the electromagnetic radiation passes through the sample solution, some energy will be absorbed selectively and the remaining will be transmitted. When electromagnetic radiation interacts with a molecule at a suitable frequency so that the energy of the molecule is increased to a higher level, energy absorption by the molecule occurs. Only light with specific wavelengths will be absorbed. If the molecule absorbs visible and UV light, there will be a transfer of electrons from the ground state to the excited state. If the absorbed light is infrared, the electrons in atoms will only vibrate. The analysis of transmission will bring us to the absorption value which depends on the wavelengths of initial light used. Absorbance is the ratio of light intensity absorbed to the initial light. The correlation between transmittance, absorbance and light intensity is formulated by Lambert-Beer as shown in the Equation (1) as discussed previously.



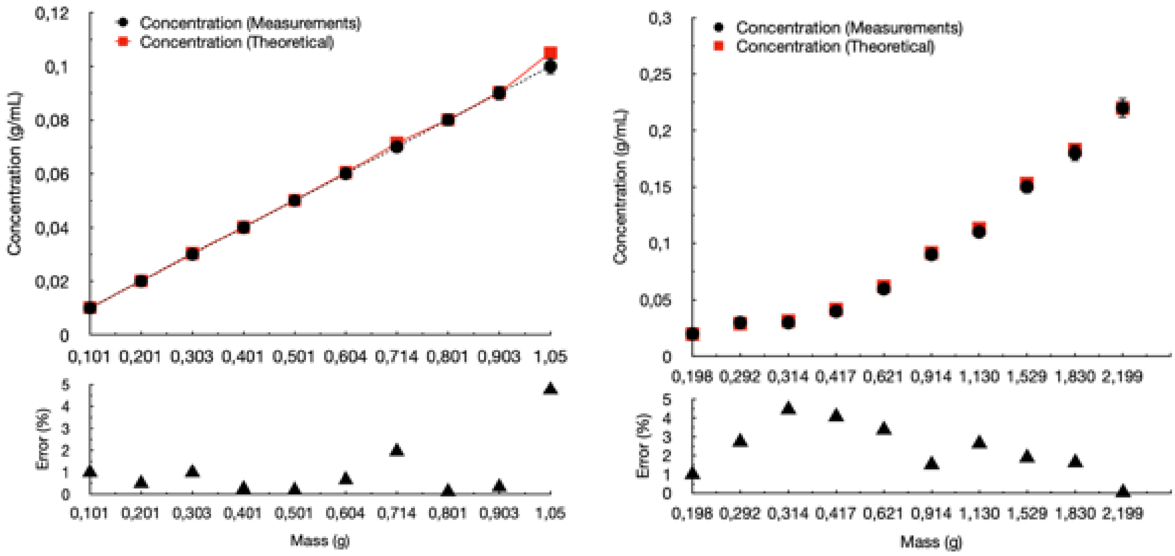
(a) (b)

Fig. 9. Measurement results of Transmittance (T, black circle dot) and absorbance (A, red triangle) of (a) coffee solution (acidity) and (b) bicarbonate of soda solution (alkalinity)

The transmittance is measured by spectABC by comparing the initial light (reference) and transmitted intensity of light after passing through the sample. Then, the absorbance value is derived from the transmittance value using Equation (1). The samples that are used in this research are arabica coffee and bicarbonate of soda (NaHCo3) powder. Sample is prepared by dissolved the various mass of coffee (0,101 to 1,05 gram) and bicarbonate of soda powder (0.198 to 2.199 gram) in 10 ml distilled water so we have various sample with different concentration in the measurement. The measurement results are shown in Figure 9 for both sample solution. According to Figure 9, absorbance is directly proportional to the amount of sample while transmittance is inversely proportional to the amount of sample. Both sample (a) and (b) show the same absorption band characteristics. It can be seen how the signals forms are very similar between them conclude the spectABC system could be used in all range of acidity-alkalinity measurements. The intensity of the transmitted light is proportional to the thickness and density of the materials [19]. Therefore, absorbance value depends on the concentration or density of substances contains in the material solution. If more substances exist in the sample, then more substance molecules will absorb light intensity at a specific wavelength. The amount of light absorbed at a particular wavelength is proportional to the number of molecules that absorb radiation. Otherwise, the amount of transmitted light intensity is inversely proportional to the number of molecules in the sample. These results meet agreement with the Lambert-Beer law and the principle of radiation interaction with matter.

3.7. Measurement of Acid-Base Concentration

We measure the concentration of the sample using spectABC and compare the results with the theoretical prediction. The samples that are used in this research are arabica coffee and bicarbonate of soda ($NaHCo_3$) powder. The sample is prepared by dissolving the coffee and bicarbonate of soda powder in 10 ml of distilled water. The variation of concentrations is listed in Table 1. The theoretical prediction is based on the standard density formula by dividing the mass and its volume. The comparison of concentration measured by spectABC and theoretical prediction is shown in Figure 10 (a) for a coffee solution and Figure 10 (b) for the bicarbonate of soda solution. The sample preparation has been explained in the previous section. The use of a pH indicator solution helps us to obtain more detail and clear color gradation which depends on the acidic and alkalinity levels of the sample. The levels of acidic and alkalinity itself depend on the amount of acid and base concentration in the solution.



(a) (b)

Fig. 10. Measurement results of (a) coffee solution and (b) Bicarbonate of soda concentrations measured by SpectABC (Measurements, black circle dot) compared to the calculated concentration (Theoretical, red square dot) obtained theoretically and the percentage of measurement error (black triangle) by comparing both results

According to Figure 10 (a), the coffee solution concentration is varied from 0,01 grams/mL to 0.105 grams/mL. The relative error percentage of the measurement is reported to be less than 4.8% as shown in the bottom plot of Figure 10 (a) marked by a black triangle. The average percentage of accuracy is found to be 98.92% with the minimum accuracy percentage is 95.24% and the maximum accuracy percentage is 99.88%. Similarly, the bicarbonate of soda concentration is also measured and compared to the theoretical prediction. Figure 10 (b) shows the measurement results of bicarbonate of soda concentration. The concentration varies 0.02 grams/mL to 0.22 grams/mL. Just like the previous sample, according to Figure 10 (b), the measurement error percentage is less than 4.46%. The average percentage of accuracy is found to be 97.67% with the minimum accuracy percentage is 95.54% and the maximum accuracy percentage is 99.95%. Overall measurements have consistently high accuracy (above 97%) convincing the spectABC to have a very good performance and can be used in all range of acidity measurements.

IV. CONCLUSION

A photodiode-based spectrophotometer so-called spectABC has been successfully developed. The spectABC consists of two black compartments that are used for the photodiode sensor, LED as a light source, and polystyrene cuvette sample in between. Another compartment is used to place electronic circuits as well as microcontrollers. The spectABC use abundant low-cost components with compact electronic circuit and compartments so that the measurement process will be efficient and user-friendly. Even though the cost of the component is relatively low, the spectABC has good performance and high sensitivity. It is due to careful and strict calibration and sensor characterization conducted. The relative error percentage of the measurement is reported to be less than 4.8% in the measurement of the coffee solution. The average percentage of accuracy is found to be 98.92%. In the measurement of bicarbonate of soda concentration, the measurement error percentage is less than 4.46%. The average percentage of accuracy is found to be 97.67%. Overall measurements have consistently high accuracy which is above 97%. The result of transmittance and absorbance measurement concludes to meet an agreement with the Lambert-Beer law, where the amount of light absorbed is proportional to the number of molecules (related to the density and concentration) that absorb radiation. In addition, the amount of transmitted light intensity is inversely proportional to the number of molecules in the sample.

ACKNOWLEDGMENT

This research is supported by Universitas Negeri Padang under the PNBP project with the Number of Contract: 1157/UN35.15/LT/2023.

REFERENCES

[1] Y. Shi, D. Pu, X. Zhou, and Y. Zhang, “Recent Progress in the Study of Taste Characteristics and the Nutrition and Health Properties of Organic Acids in Foods,” Foods, vol. 11, no. 21, p. 3408, Oct. 2022, doi: 10.3390/foods11213408.
[2] A. Zapaśnik, B. Sokołowska, and M. Bryła, “Role of Lactic Acid Bacteria in Food Preservation and Safety,” Foods, vol. 11, no. 9, p. 1283, Apr. 2022, doi: 10.3390/foods11091283.
[3] A. Djukic-Vuković, D. Mladenovic, B. Lakicevic, and L. Mojovic, “Lactic acid bacteria: from food preservation to active packaging,” IOP Conf. Ser. Earth Environ. Sci., vol. 854, no. 1, p. 012025, Oct. 2021, doi: 10.1088/1755-1315/854/1/012025.
[4] S. Chen et al., “Study on analysis of acid number of transformer oil by temperature titration,” IOP Conf. Ser. Earth Environ. Sci., vol. 300, no. 4, p. 042025, Jul. 2019, doi: 10.1088/1755-1315/300/4/042025.
[5] Yulkifli, D. A. Wulandari, R. Ramli, S. B. Etika, and C. Imawan, “A simple colorimeter based on microcontrollers to detect food dyes,” J. Phys. Conf. Ser., vol. 1528, no. 1, p. 012066, Apr. 2020, doi: 10.1088/1742-6596/1528/1/012066.
[6] A. Ishak, K. Siregar, Asfriyati, and M. Safira, “The Effect of Sugar Concentration, Citric Acid Concentration and Storage Time on Orange Syrup’s pH Using Completely Randomized Factorial Design,” IOP Conf. Ser. Mater. Sci. Eng., vol. 1003, no. 1, p. 012106, Dec. 2020, doi: 10.1088/1757-899X/1003/1/012106.
[7] S. Melia, I. Juliyarsi, Y. Fitri Kurnia, Y. Endra Pratama, and H. Azahra, “Examination of Titratable Acidity, pH, Total Lactic Acid Bacteria and Sensory Properties in Whey Fermented with Probiotic Pediococcus acidilactic BK01,” Adv. Anim. Vet. Sci., vol. 10, no. 1, 2021, doi: 10.17582/journal.aavs/2022/10.1.114.119.
[8] S. R. Waterman and P. L. C. Small, “Acid-Sensitive Enteric Pathogens Are Protected from Killing under Extremely Acidic Conditions of pH 2.5 when They Are Inoculated onto Certain Solid Food Sources,” Appl. Environ. Microbiol., vol. 64, no. 10, pp. 3882–3886, Oct. 1998, doi: 10.1128/AEM.64.10.3882-3886.1998.
[9] P. A. Lund et al., “Understanding How Microorganisms Respond to Acid pH Is Central to Their Control and Successful Exploitation,” Front. Microbiol., vol. 11, p. 556140, Sep. 2020, doi: 10.3389/fmicb.2020.556140.
[10] J.-M. Park et al., “Determination of Shelf Life for Butter and Cheese Products in Actual and Accelerated Conditions,” Korean J. Food Sci. Anim. Resour., vol. 34, no. 2, pp. 245–251, Apr. 2014, doi: 10.5851/kosfa.2014.34.2.245.
[11] N. Johnson and E. Bruno, “Novel Use of Ophthalmic pH Paper to Diagnose Malicious Caustic Ingestion in a Pediatric Patient,” Clin. Pract. Cases Emerg. Med., vol. 2, no. 1, pp. 39–42, Jan. 2018, doi: 10.5811/cpcem.2017.11.36367.
[12] S. Ka, A. Ki, and R. Ok, “pH Indicators: A Valuable Gift for Analytical Chemistry,” Saudi J. Med. Pharm. Sci., vol. 06, no. 05, pp. 393–400, May 2020, doi: 10.36348/sjmps.2020.v06i05.001.
[13] P. M. Nowak, I. Biel, G. Kózka, M. Klag, and M. Woźniakiewicz, “Influence of pH measurement inaccuracy on the values of acidity constant determined on the basis of electrophoretic and thermophoretic data,” Microchem. J., vol. 181, p. 107689, Oct. 2022, doi: 10.1016/j.microc.2022.107689.
[14] S. Feng, S. Xiang, X. Bian, and G. Li, “Quantitative analysis of total acidity in aqueous lactic acid solutions by direct potentiometric titration,” Microchem. J., vol. 157, p. 105049, Sep. 2020, doi: 10.1016/j.microc.2020.105049.
[15] A. Kotani, F. Kusu, K. Takamura, and H. Hakamata, “Review—A Portable Voltammetric Sensor for Determining Titratable Acidity in Foods and Beverages,” J. Electrochem. Soc., vol. 167, no. 3, p. 037517, Jan. 2020, doi: 10.1149/2.0172003JES.
[16] M. Ma’firah, A. P. Lubis, and R. Zainul, “Acid-Base Learning Outcomes to be Improved Through a Guided Discovery-Based Content Learning System,” J. Phys. Conf. Ser., vol. 2582, no. 1, p. 012065, Sep. 2023, doi: 10.1088/1742-6596/2582/1/012065.
[17] M.-T. Monaghan, K. Brogan, D. Lockington, A. P. Rotchford, and K. Ramaesh, “Variability in measuring pH using litmus paper and the relevance in ocular chemical injury,” Eye, vol. 34, no. 11, pp. 2133–2134, Nov. 2020, doi: 10.1038/s41433-019-0737-z.
[18] M. B. Sari, R. Wirawan, A. Waris, H. J. Kim, and M. Djamal, “Simulation of Void Detection System using Gamma-Ray Compton Scattering Technique,” J. Eng. Technol. Sci., vol. 51, no. 3, pp. 369–379, Jun. 2019, doi: 10.5614/j.eng.technol.sci.2019.51.3.5.

[19] Yulkifli, K. S. Dewantara, M. B. Sari, Ramli, F. Razi, and W. Handayani, "A Low-cost Digital Spectrophotometer for Heavy Metal Absorbance Measurements," Instrum. Exp. Tech., vol. 66, no. 1, pp. 147–155, Feb. 2023, doi: 10.1134/S0020441223010256.

[20] A. B. D. Nandiyanto, R. Zaen, R. Oktiani, A. G. Abdullah, and L. S. Riza, "A Simple, Rapid Analysis, Portable, Low-cost, and Arduino-based Spectrophotometer with White LED as a Light Source for Analyzing Solution Concentration," TELKOMNIKA Telecommun. Comput. Electron. Control, vol. 16, no. 2, Art. no. 2, Apr. 2018, doi: 10.12928/telkomnika.v16i2.7159.

[21] S. Di Nonno and R. Ulber, "Portuino-A Novel Portable Low-Cost Arduino-Based Photo- and Fluorimeter," Sensors, vol. 22, no. 20, p. 7916, Oct. 2022, doi: 10.3390/s22207916.

[22] B. J. Place, "Activity Analysis of Iron in Water Using a Simple LED Spectrophotometer," J. Chem. Educ., vol. 96, no. 4, pp. 714–719, Apr. 2019, doi: 10.1021/acs.jchemed.8b00515.

[23] E. K. Grasse, M. H. Torcasio, and A. W. Smith, "Teaching UV–Vis Spectroscopy with a 3D-Printable Smartphone Spectrophotometer," J. Chem. Educ., vol. 93, no. 1, pp. 146–151, Jan. 2016, doi: 10.1021/acs.jchemed.5b00654.

[24] J. Chanla, M. Kanna, J. Jakmunee, and S. Somnam, "Application of smartphone as a digital image colorimetric detector for batch and flow-based acid-base titration," Jan. 2019, Accessed: May 15, 2024. [Online]. Available: http://cmuir.cmu.ac.th/jspui/handle/6653943832/67635

[25] A. Yuniati and R. Rifai, "Study of simple spectrophotometer design using LDR sensors based on arduino uno microcontroller," J. Phys. Conf. Ser., vol. 1153, no. 1, p. 012099, Feb. 2019, doi: 10.1088/1742-6596/1153/1/012099.

[26] Yulkifli, P. Kahar, R. Ramli, S. B. Etika, and C. Imawan, "Development of color detector using colorimetry system with photodiode sensor for food dye determination application," J. Phys. Conf. Ser., vol. 1185, p. 012031, Apr. 2019, doi: 10.1088/1742-6596/1185/1/012031.

[27] D. González-Morales, A. Valencia, A. Díaz-Nuñez, M. Fuentes-Estrada, O. López-Santos, and O. García-Beltrán, "Development of a Low-Cost UV-Vis Spectrophotometer and Its Application for the Detection of Mercuric Ions Assisted by Chemosensors," Sensors, vol. 20, no. 3, p. 906, Feb. 2020, doi: 10.3390/s20030906.

[28] J.-J. Poh, W.-L. Wu, N. W.-J. Goh, S. M.-X. Tan, and S. K.-E. Gan, "Spectrophotometer on-the-go: The development of a 2-in-1 UV–Vis portable Arduino-based spectrophotometer," Sens. Actuators Phys., vol. 325, p. 112698, Jul. 2021, doi: 10.1016/j.sna.2021.112698.

[29] A. Sifa Fauziyyah and Yohandri, "Design of automatic infusion monitoring system based on Arduino," J. Phys. Conf. Ser., vol. 1528, no. 1, p. 012025, Apr. 2020, doi: 10.1088/1742-6596/1528/1/012025.

[30] M. Patel, A. Sakaamini, M. Harvey, and A. J. Murray, "An experimental control system for electron spectrometers using Arduino and LabVIEW interfaces," Rev. Sci. Instrum., vol. 91, no. 10, p. 103104, Oct. 2020, doi: 10.1063/5.0021229.

[31] V. Alenkov et al., "Alpha backgrounds in the AMoRE-Pilot experiment," Eur. Phys. J. C, vol. 82, no. 12, p. 1140, Dec. 2022, doi: 10.1140/epjc/s10052-022-11104-3.

[32] L. Yuliantini, M. B. Sari, M. Djamal, K. Boonin, P. Yasaka, and J. Kaewkhao, "Physical properties of Gd3+ ion doped fluorotellurite glass and their radiation shielding parameter," presented at the THE 3RD INTERNATIONAL CONFERENCE ON SCIENCE, MATHEMATICS, ENVIRONMENT, AND EDUCATION: Flexibility in Research and Innovation on Science, Mathematics, Environment, and education for sustainable development, Surakarta, Indonesia, 2023, p. 100001. doi: 10.1063/5.0112874.

[33] P. Listiaji and G. B. Suparta, "Low-cost imaging spectrophotometer system for absorbance measurement," J. Phys. Conf. Ser., vol. 1567, p. 042093, Jun. 2020, doi: 10.1088/1742-6596/1567/4/042093.

[34] D. HA et al., "Development of thermal neutron shield with low radioactivity," J. Instrum., vol. 17, p. P10041, Oct. 2022, doi: 10.1088/1748-0221/17/10/P10041.

[35] M. Hardyan and F. A. Haqqi, "Arduino based smart home security design using biometric recognition," J. Phys., 2022.