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Determination of refractive index on three mediums based on the principle of refraction of light

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Abstract. This study aims to develop a tool to determine the refractive index and height of objects in three media based on the principle of light refraction. The method used was an experimental method. The results showed the refractive index values of the three media were quite accurate when compared to the absolute refractive index. The relationship of the angle of the incident ray was directly proportional to the angle of the refractive ray. The angle of light produced will be greater if the value of the given beam angle was greater. Thus, the set of refractive index laboratory tools developed is said to be good and suitable to be implemented in schools to explain the concept of the refractive index of light.

1. Introduction

Physics is a science-based on experiments [1]. One method of learning physics using tools in learning is the experimental method [2]. Experimental activities in the laboratory can perform smoothly if laboratory equipment is available [3]. But the fact is not all schools which have this equipment completely, or, in several cases, there are not all physic concepts which have experiment tools such as in refracting concept. This factor caused many students who have difficulty in problem-solving [4].

One of the physics concepts that are abstract, and needs to be practiced through experiments is the refraction of light [5]. Besides, the number of misconceptions on this concept required students to conduct an experiment activity in order to make it easier to learn [6]. Light has many phenomena that student can learn [7]. The fundamental concepts of refraction of light are based on the results of invention by Dutch scientist Willebrord Snellius, the well-known as the first law of Snellius and the second law of Snellius [8]. The refraction of light events occurs in optical substances such as air, water, and glass [9]. Refraction of light occurs because of differences in the speed of light on the two media. The speed of light in a dense medium is slower than the speed of light in the air medium [10]. In general, the speed of light in all materials is slower than the maximum speed in vacuum [11].

The most teachers explain of light refraction topic, usually, using glass filled with liquid and then inserted a pencil [4]. However, that activities are only able to show the refraction phenomenon, but do not explain the relationship between variables such as the angle of incidence, the angle of refraction, and the refractive index. So, its usefulness to solve related problems in daily life.

The teacher has done a simple experiment, by using a simple laboratory tools, to provide students with a good learning experience on the topic of refractive index. As the result, student will be able to understand the refractive index topic better [12]. The refractive index experiments can improve student understanding, especially in the discussion and implementation of the optics [13]. The refractive index is one of several important optical properties of a medium [14]. The refractive index is a measurement of speed of light in a liquid compared to when it is in the air [15] and is one of the most important optical properties of a medium [16]. The refractive index in a medium is often defined as the ratio between the speed of light in a vacuum to the speed of light in a medium [17].

The physics laboratory in schools has developed a simple tool to test the refractive index of the liquid [18]. In Indonesia, most teachers prove the concept of refraction using only a pencil dipped in a clear glass filled with water. There are several researches of laboratory tools that used to determine the refractive index, including with a CD lattice, refractometer, parallel plan glass, and optical fiber.

Previous research carried out a refractive index experiment tools with a fairly complex step or set up. However, when the tool is implemented in laboratory activities, there are several obstacles for example, it can only be used to determine the refractive index in one media [4]. The novelty of the research is that the set of tools developed is derived from general equipment that can be found in everyday life. The equipment made does not require relatively expensive costs. This tool can measure the refractive index on three mediums at once, namely, on the medium of air, solid and liquid. In the solid medium, the researchers used a glass that had a thickness of more than 15 mm. Besides, researchers also put an object in the water so that students who will do the practicum can measure pseudo height and actual height of objects in the water that is affected by the refractive index. The purpose of development the tool is to make it easier, for students, to determine the refractive index by only using one experiment tool to in three mediums at once.

Methods

The research method used is an experimental method where the delivery of teaching is done by experimenting to find out for yourself what has been learned. Students can find for themselves what was learned individually [19]. This method starts by designing a light refraction tool with steps like in Figure 1. The making this light refraction tool starts by first determining the tools and materials, which consist of a cookie jar, glass, laser, protractor, ruler, object, wooden board, water, and rope. The light refraction device that has been created is shown in Figure 1.

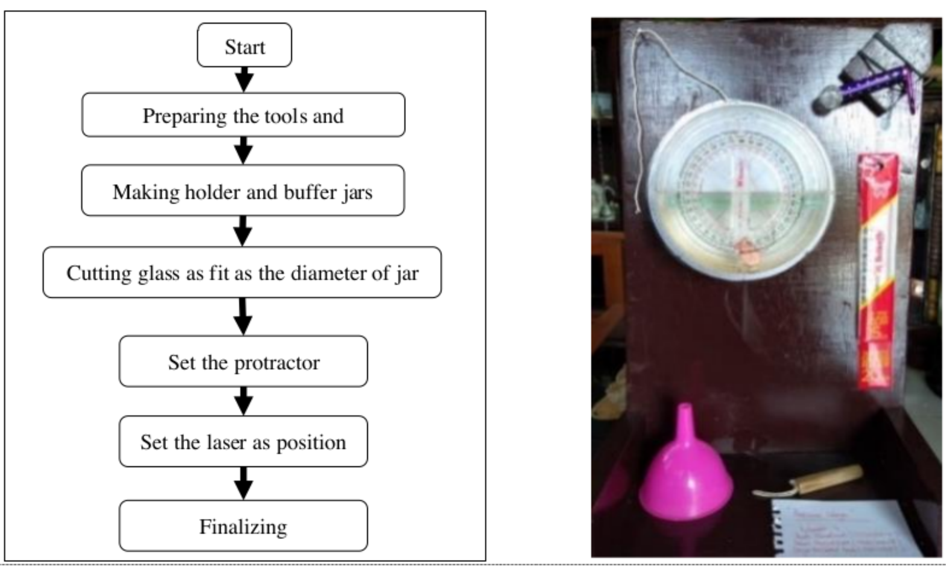

Figure 1. The steps-by-step process (left) and the tool (right)

The design considered the intended uses, practicality in the use and utilization of the experimental set in the learning process. The tool was designed to be used in three mediums which are air, glass, and water. This tool works based on the Snellius' refraction principle which reads incident rays, normal lines, and refractive rays located on a flat plane. A comparison of sinus of incident ray and its refraction is a fixed number that is called the refractive index [20]. The incident beam from the laser will be refracted or deflected to form a refractive angle (the angle formed between the refractive beam and the normal line) [21]. The comparison of the angle of the incident ray and the angle of the refractive ray this then produces the refractive index value. The value of the refractive index depends on the medium in which it passes. The tight the medium is traversed, the bigger the refractive index. Whereas if the media being passed is loose, the value of the refractive index is smaller [22]. The refractive index value of a medium can be determined using the law equation Snellius [23].

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_r}{n_i} \tag{1}$$

$$\sin\theta_i \cdot n_i = \sin\theta_r \cdot n_r \tag{2}$$

Here, we can determine the height of an object. The equation used is shown as follows

$$h = \frac{\tan\theta_1}{\tan\theta_2} h' \tag{3}$$

with θ_1 = the viewing angle (°), θ_2 = the refractive angle (°), n_i = the refractive index of the first medium, n_r = the refractive index of the second medium, h' = the height of the image (m), h = the height of object (m).

3. Result and Discussion

The refractive index experiment tool has been made. The repeated testing is carried out to ensure that this tool can be used and worked correctly. The measurements, the data that are collected used the toll, are measuring the angle of the incident ray and the angle of refractive ray. Three mediums passed consist of air, glass, and water at the same height. The doing variations in the incident light are at an angle of 30°, 45°, and 60°. The results of the observation are shown in Table 1.

Table 1. The measurement results use a light refracting tool

No	Altitude (m)	1st Variations		2nd Variations		3rd Variations	
		Incident Angle (°)	Refractive Angle (°)	Incident Angle (°)	Refractive Angle (°)	Incident Angle (°)	Refractive Angle (°)
1	5 x 10^{-2}	30	20	45	25	60	30
2	5 x 10^{-2}	30	20	45	25	60	35
3	5 x 10^{-2}	30	20	45	25	60	35
4	5 x 10^{-2}	30	15	45	25	60	30
5	5 x 10^{-2}	30	15	45	30	60	35
6	5 x 10^{-2}	30	15	45	25	60	30
7	5 x 10^{-2}	30	15	45	30	60	30
8	5 x 10^{-2}	30	15	45	30	60	35
9	5 x 10^{-2}	30	20	45	30	60	30
10	5 x 10^{-2}	30	20	45	25	60	30
11	5 x 10^{-2}	30	20	45	25	60	30
12	5 x 10^{-2}	30	20	45	25	60	30
13	5 x 10^{-2}	30	20	45	25	60	30
14	5 x 10^{-2}	30	20	45	25	60	30
15	5 x 10^{-2}	30	20	45	25	60	30
16	5 x 10^{-2}	30	20	45	25	60	30
17	5 x 10^{-2}	30	20	45	25	60	35
18	5 x 10^{-2}	30	20	45	25	60	30
19	5 x 10^{-2}	30	20	45	25	60	30
20	5 x 10^{-2}	30	20	45	25	60	35

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Each variation of the angle of the incident ray has a different value of the refractive beam angle. At the altitude 5 x 10-2 m with angles coming up it 30° produces a refractive angle value 15° and 20°. The highest angle of the refractive ray is valued 35° at the angle of incident ray 60° while the lowest angle of the refractive ray is valued 15° at the angle of the incident 30°. So, if the angle of the incident ray is enlarged, the value of the angle of the refractive ray will increase. Based on the data, it can be concluded that the incident ray is directly proportional to the refractive light, and this is also the opposite [24]. By using the measurement data, it can be calculated the height of the object and the refractive index of each medium. This result can be seen in Table 2.

Table 2. The results of measurements of the refractive index and the actual height of each object

No	Viewing rays (°)	Refractive ray (°)	Image height (m)	Object height (m)	Air refractive index	Glass refractive index	Water refractive index
1	30	15	5 x 10^{-2}	10.7 x 10^{-2}	0.78	1.93	2.90
2	30	20	5 x 10^{-2}	7.9 x 10^{-2}	1.02	1.46	2.19
3	45	25	5 x 10^{-2}	10.7 x 10^{-2}	0.90	1.67	2.51
4	45	30	5 x 10^{-2}	8.6 x 10^{-2}	1.06	1.41	2.12
5	60	30	5 x 10^{-2}	15.0 x 10^{-2}	0.87	1.73	2.60
6	60	35	5 x 10^{-2}	12.3 x 10^{-2}	0.99	1.51	2.26
Average refractive index calculation					0.94	1.62	2.43

The highest object is at the angle of the incident ray 60° with a refractive ray angle of 35° which value is 12.3 x 10^{-2} m, while the lowest object is at the angle of incident ray 30° with the angle of refractive ray 20° which value is 7.9 x 10^{-2} m. Table 2 shows the measured height of each object. The actual height of the object becomes deeper at the surface of the water than the height of the object's shadow. This is caused by the refraction of light that passes through the surface of the water, which causes bending of the light. So, that objects look closer than in fact, and the object is located far from the surface of the water [8]. This bending light occurs due to differences in the density of the medium through which light is passed [25]. The height of each object on the surface of the water is affected by the angle of incidence. The greater the angle of incidence, the deeper objects looks from the surface. Conversely, the smaller the angle of incidence, the shallower object looks to the surface.

The results of calculations on the refractive index have slightly different values in each angle variation of the incident ray. The average yield of the refractive index produced does not have much difference from the absolute refractive index for the three mediums. The absolute refractive index in the air is 1 and in glass is 1.5 [26]. While the absolute refractive index in water is 1.33 [27]. This is not in accordance with the average refractive index produced where the refractive index of water obtained is 2.43. The result shows if we compare it with observations relating to the refractive index on the glass medium as did previous research by Faradhillah, the resulting refractive index has the same value [28].

The water refractive index obtained from this study, when compared with previous studies conducted by Radiyonoa has a different value [29]. Based on the results of research, the error value between the measurement and reference results in the refractive index of the air reaches 6%, while the refractive index of the glass reaches 0%, but at the water refractive index, the percentage of errors reaches 8.2% with the absolute refractive index. The difference in the refractive index is due to the result obtained is a comparison of the angle of the incident ray and the refractive ray angle with its absolute refractive index so that the resulting refractive index is a relative refractive index [30]. Besides, the difference in the refractive index is caused by the speed of light speed in each medium (different samples), where the speed of light at vacuum speed is faster than the speed of light when passing through a medium [27].

The inaccuracy in making tool and measurements can also cause the value of the refractive index of water is different in every angle of the viewing. However, the refractive index in the other medium does not experience too much difference in value from the absolute refractive index value. The advantage of our tool uses three different mediums to determine the refractive index and can measure heights of the

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image and heights of objects that are in the water. The drawback of the tools we use is less precision in the results of the third medium refractive index, which causes the value of the refractive index far different from the absolute refractive index. In further research, it is recommended to modify the tool so that the resulting refractive index value corresponds to its absolute refractive index, especially on the third medium (water).

4. Conclusion

We have succeeded in conducting research on making a tool from simple materials and equipment that are easily found in everyday life to determine the refractive index and height of objects on three mediums (air, glass, and water). Based on the results of the study, the relationship of the angle of the incident ray is directly proportional to the angle of the refractive ray. Based on the results of the study, the relationship of the angle of the incident ray is directly proportional to the angle of the refractive ray. The refractive index on denser media will have a greater refractive index value. Only the refractive index value of water has a greater value than the glass medium. However, the air and glass medium have a value that corresponds to the absolute refractive index. Thus, the set of tools made can prove the value of the absolute refractive index and is said to be suitable for learning of students.

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