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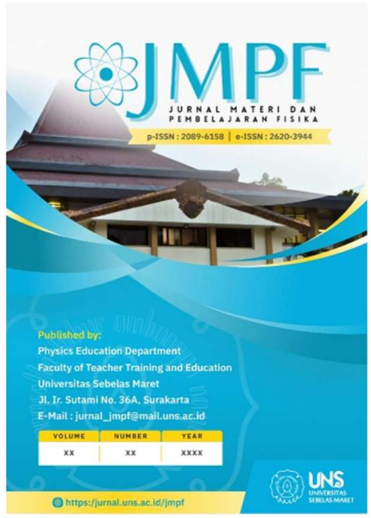

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Jurnal Materi dan Pembelajaran Fisika is providing a platform that welcomes and acknowledges high-quality empirical original research papers about education written by researchers, academicians, professionals, and practitioners from all over the world.

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Focus and scopes of **Jurnal Materi dan Pembelajaran Fisika** are (1) physics learning and education, (3) learning technologies, (3) assessment of physics education, and (4) physics.

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Focus and Scope

The scope of the articles published in **Jurnal Materi dan Pembelajaran Fisika** deals with a broad range of topics in the fields of physics learning education, learning technologies, assessment of physics education and another section related to the method of learning in physics education.

Physics Learning and Education: An area of pedagogical research that seeks to improve those methods. Significant innovative findings related to physics education, with related research objects: the application of learning innovations with the latest learning models, methods and technologies, analysis of misconceptions, analysis of learning tools, and analysis of the implementation of school programs related to learning physics in high school environments

Learning Technologies: Innovative development with research objects: teaching materials/media, teaching aids and learning tools based on technological pedagogical content knowledge (TPACK) for physics learning or extracurricular activities in high school environments.

Assessment of Physics Education: Development of assessment instruments and analysis of the results of their application in physics learning in secondary schools, assessment for learning using classical test theory (CTT), item response theory (IRT), and multidimensional item response theory (MIRT).

Physics: Research in the physics area and analysis of the results from their applications also.

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Simple Measurements of Refractive Index of Glycerine using a Spherical Flask

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Abstract. The refractive index of glycerine is measured using a spherical lens. This setup functions as a convex lens. Focal length measurements are carried out using two standard methods, namely the direct method and the lens formula method. First, the focal length is determined directly using parallel rays. Second, we measure the object distance and the image distance. From the obtained focal length, the refractive index of the glycerine is then calculated. Using various concentrations, we found that the refractive index of glycerine depends linearly on its concentration linearly. The refractive index of pure water (0% glycerine) and glycerine at concentrations of 60%, 80%, and 100% are found to be (1.33±0.02), (1.42±0.03), (1.46±0.03), (1.49±0.04), respectively. This experiment uses simple equipment available in most laboratories and can be carried out in schools.

Keywords: lens, focal length, refractive index, glycerine, spherical flask

INTRODUCTION

Standard textbooks discuss lenses by introducing the refractive index and radius of curvature. However, most laboratory manuals do not provide experimental demonstrations of this relationship. Usually the purpose of the experiment is to determine the focal length of a particular lens (Armitage, 1982). Here, students do not learn the characteristics of the lens. Students are typically limited to measuring focal length without exploring its dependence on lens parameters. This situation is caused, among other things, by the lens itself. Usually, lenses are made of glass, and the size and refractive index cannot be changed. To study lens characteristics, the laboratory should provide a set of lenses with different curvature radii and materials.

Various experiments show parameters related to lenses, such as focal length, lens magnification, and applications. To see small objects, Limsuwan uses a lens made from a measuring flask filled with water (Limsuwan et al., 2012). With this kind of lens, they observed tiny objects floating on a liquid sample. The magnification and focal length of the lens can also be studied with water pearls (Bolotin, 2012). Uchida created a variable focal length lens using lids for food preservation. This simple lens was used as a model for the human eye (Uchida, 2017). Even water droplets can act as lenses (Freelan et al., 2020). Recently, a spherical flask was used as a lens to determine the refractive index of a liquid (Santosa, 2021a).

Measurement of the refractive index of liquids is often carried out in various methods. Simple ones measure directly using Snell's Law. A laser pointer was used to observe the path of light in an empty box and a box filled with water. This path difference was used to measure the refractive index of water (Newburgh, R., Rueckner, W., Peidle, J., and Goodale, 2000). Similarly, Gluck used a beaker filled with fluid. Then the refractive index of the liquid was determined by observing the "broken" in the immersed rod (Gluck, 2011). The refractive index of water, ethanol, and glycerol had been measured using a graduated cylinder and a beaker (An, 2017). In this case, the magnified image of the graduated cylinder formed when the liquid was poured into the beaker was used to determine the refractive index. More complex devices were specially made such as prisms using the autocollimation method (Cheng, 2014) and the diffraction method (Singh, 2004).

Glycerine is well known as a viscous liquid. Because of its viscosity, glycerine is widely used as a viscosity measurement object in practical applications (Ferreira et al., 2017; Magazu, and Migliardo, 2008; Soares et al., 2012). From an optical point of view, the refractive index depends on the density, molecular structure, and wavelength. Denser liquids have a higher refractive index. Measurement of the refractive index of glycerine has been carried out using various methods, generally using Snell's Law. In simple terms, Chanprasert (2015) applied Snell's law to measure the refractive index of glycerine. The experiment set consists of an acrylic box, a Laser source, and a plate mirror. The measurement was performed with visual observation. Likewise, Ortega et al (2019) measured the refractive index of glycerine based on Snell's Law, which was carried out automatically with an Arduino Uno card.

For teaching purposes, this article will discuss the measurement of the refractive index of glycerine using a spherical flask as a lens (Santosa, 2021a). In contrast to the previous article, this measurement is simple and does not require additional equipment such as cameras and photo analyzers. Our setup consists of standard equipment commonly used for optical experiments. Therefore, this experiment is suitable to be taught and can be carried out in schools. This experiment can also increase students' understanding of the characteristics of lenses. Students learn physical parameters, e.g. curvature and refractive index, that affect the focal length of a lens.

METHOD

A biconvex lens presented in Figure 1 has a thickness d, a radius of curvature R_1, and R_2. The refractive index of the lens and the surrounding medium are n and n_m, respectively. The focal length f of this lens follows a well known formula equation (1) (Bolotin M, 2012; Ivanov and Nikolov, 2015; Jenkin and White, 1957).

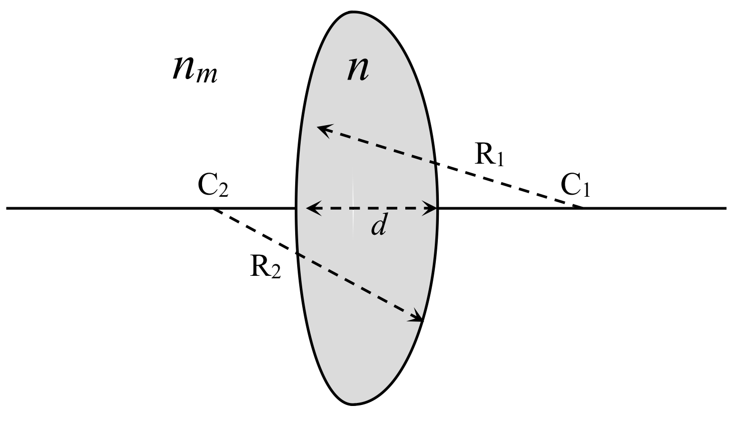

Figure 1. A biconvex lens of radius curvature R_1 and R_2 with refractive index n and the surrounding medium's refractive index n_m. The center of curvature for the first and second surface are C_1 and C_2.

$$\frac{1}{f} = \left(\frac{n}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n - n_m)\,d}{n\,R_1\,R_2}\right) \quad [1]$$

In the special case R_1 is the same as R_2 the lens become a ball shape lens of radius curvature R as shown in Figure 2. Here the center C_1 and C_2 coincide in O as the center of the lens.

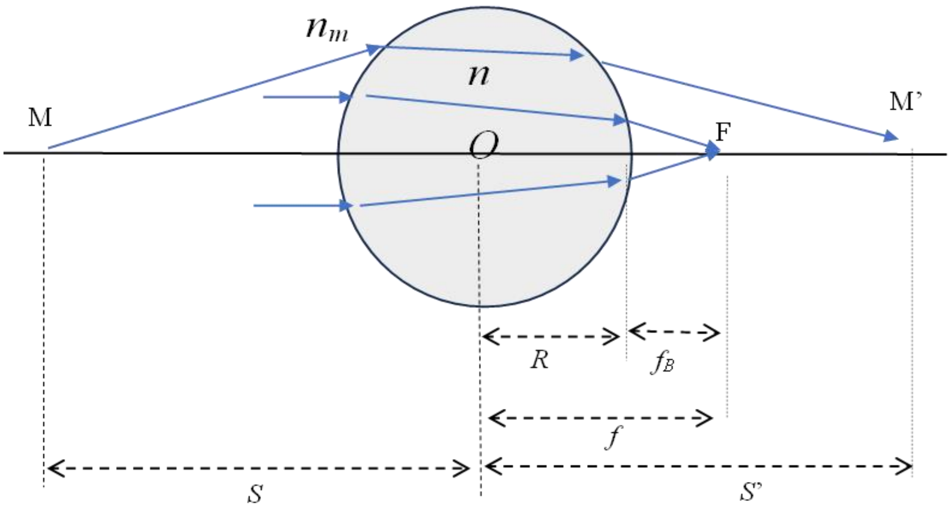

Figure 2. A ball-shaped lens of radius curvature R with refractive index n and the surrounding medium's refractive index n_m. O is the center of the lens, F is the focus, and f_b is the back focal length.

Following Figure 2, this ball shape gives $R_1 = -R_2 = R$ and the thickness of the lens is $d=2R$. If the lens is placed in the air which is $n_m = 1$, equation (1) becomes

$$\frac{1}{f} = (n-1)\left(\frac{2}{R} - \frac{2\,(n-1)}{R\,n}\right) \quad [2]$$

$$\frac{1}{f} = \frac{2}{R\,n}(n-1) \quad [3]$$

$$f = \frac{n}{2\,(n-1)}\,R \quad [4a]$$

or

$$f = \frac{R}{2}\left(1 + \frac{1}{n-1}\right) \quad [4b]$$

The refractive index follows

$$n = \frac{2\,f}{2\,f - R} \quad . \quad [5]$$

Equation (4a and 4b) shows that focal length f is depends on the radius of curvature and the refractive index. Following equation (5), in order to determine the refractive index, ones should measure the focal length. For the pedagogical purposes the measurement can be done using standard method i.e. directly determine the focus of the lens using a parallel beam. The focal length can also be obtained by measuring the object distance S as well as the image distance S' (see Figure 2), In this measurement the focal length follows (Jenkin and White, 1957).

$$\frac{1}{f} = \frac{1}{S} + \frac{1}{S'} \qquad [6]$$

The experimental setup is depicted in Figure 3. We used a spherical-shaped flask containing the liquid under investigation (Santosa, 2021a). A vernier caliper was used to measure the lens's radius of curvature. We used a set standard optical instrument available in the lab i.e., a light source with a parallel beam, an object, a screen, and an optical bench. The screen mounted onto the optical bench was used to detect the image or the focus. A spherical flask was placed on a lab jack located above the optical bench. The height and the horizontal position of the flask were adjusted until the light beam was transverse in the middle.

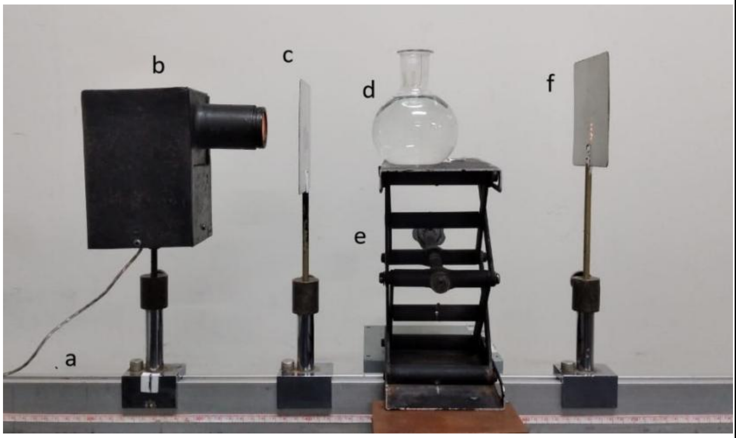

Figure 3. Experimental setup: (a) optical bench, (b) light source, (c) object, (d) liquid-filled spherical flask, (e) lab jack, (f) screen.

We applied two methods to determine the focal length *f*. In the first method, without the object we observed the beam in the screen visually. To locate the focus, the screen was moved along the bench. The distance between the obtained focus and the back surface of the flask gives the back focal length (f_b see Figure 2). The focal length of the lens then can be calculated from this back focal length f_b and the radius of curvature *R*. In the second method we placed an object between the light source and the lens. The image was inspected by moving the screen. Based on equation (6) the focal length was determined from the intercept of the graph of $1/S'$ versus $1/S$.

RESULT AND DISCUSSION

We performed various experiments related to the radius curvature and glycerine concentration. In the first experiment, a flask of radius curvature (3.08±0.05) cm was filled with water i.e., 0% of glycerine. The result of direct observation at focus is presented in Table 1. Here, as f_b is the distance between the observed focus and the back surface of the lens. This observation yields a focal length of (6.6±0.6) cm. Based on equation (5), we obtained the refractive index of water is (1.30±0.11).

Table 1. The back focal length f_b and the focal length f for the flask of radius curvature (3.08±0.05) cm filled with water.

No.	f_b (*cm*)	f (*cm*)
1	3.2	6.28
2	4.2	7.28
3	2.7	5.78

4	3.6	6.68
5	3.4	6.48

Using the same lens, image distance measurements for various object distances are presented in Table 2, and Figure 4. Note that Figure 4 is a graph of 1/S' vs 1/S instead of S' vs S. This graph shows a linear relationship with a slope of (-0.96±0.02), and an intercept of (0.150 ± 0.001) cm^{-1}. Based on equation (6), the obtained intercept gives a focal length of (6.7±0.1) cm. From this focal length, the refractive index of water is (1.30±0.01).

Table 2. The image distance *S'* for various object distances *S*. The lens is the flask of radius curvature (3.08±0.05) cm filled with water.

No.	***S*** **(*cm*)**	***S'*** **(*cm*)**
1	10.08	18.48
2	12.08	13.98
3	14.08	12.28
4	16.08	11.08
5	18.08	10.38

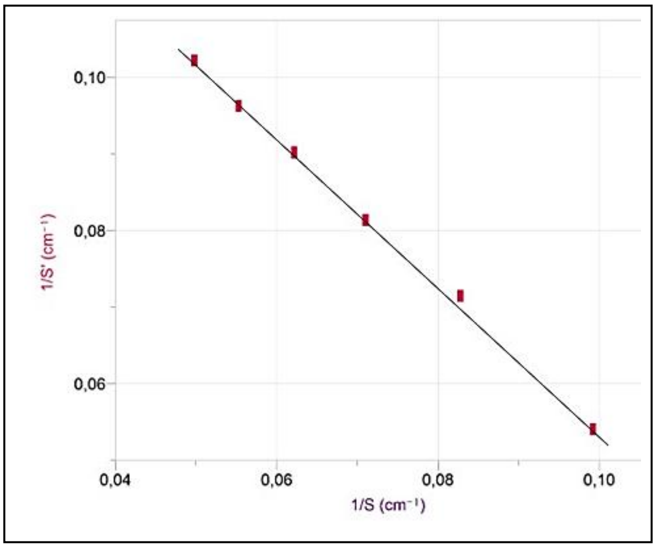

Figure 4. A graph of 1/S' vs 1/S. The lens is the flask of radius curvature (3.08±0.05) cm filled with water. Solid line is the best fit corresponding to equation (6).

The same procedure was applied to measure the refractive index of 60%, 80% and 100 % glycerine. For each concentration we used three different flasks. The focal length was measured from direct observation of focus and using equation (6). Subsequently the refractive index of glycerine was calculated using equation (5). These results are presented in Table 3.

Table 3. The focal length of the lens and refractive index of glycerine

Concentration	***R***	**Direct observation**		**Based on equation (6)**	
(%)	(*cm*)	*f* (*cm*)	n	*f* (*cm*)	n

0	3.08	6.6±0.6	1.30±0.11	6.7±0.1	1.30±0.01
	3.99	8.0±0.5	1.34±0.08	7.6±0.1	1.36±0.01
	4.16	8.3±0.4	1.34±0.06	8.2±0.2	1.34±0.03
60	3.08	5.5±0.4	1.39±0.10	5.3±0.1	1.41±0.04
	3.99	6.6±0.4	1.44±0.09	6.7±0.1	1.42±0.03
	4.16	7.2±0.6	1.41±0.12	7.1±0.2	1.41±0.03
80	3.08	5.0±0.4	1.44±0.10	5.0±0.2	1.44±0.06
	3.99	6.3±0.4	1.47±0.08	6.2±0.1	1.47±0.04
	4.16	6.9±0.3	1.43±0.07	6.5±0.1	1.47±0.01
100	3.08	4.6±0.3	1.50±0.10	4.8±0.2	1.47±0.04
	3.99	5.9±0.3	1.51±0.06	6.2±0.2	1.48±0.04
	4.16	6.3±0.3	1.49±0.07	6.2±0.2	1.51±0.05

Table 3 shows clearly that for a certain concentration, the focal length depends on the radius of curvature. A larger radius of curvature gives a longer focal length as seen in the Figure 5. This behaviour is obtained from two experiment methods namely direct observation of focus, and calculation using equation (6). There is no significant difference in both methods. This observation is in accordance with equation (4a) namely that the focal length depends linearly on the radius of curvature.

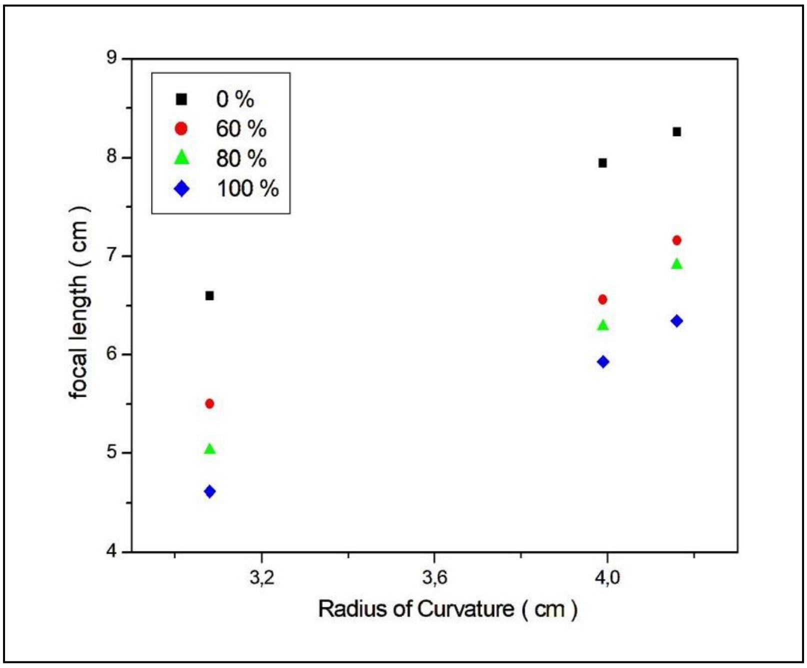

Figure 5. Focal length for different flask's radius curvatures. Notice the symbol for different glycerine concentrations.

The refractive index of glycerine is determined from the measured focal length. For the same concentration of glycerine, different flasks show relatively similar refractive index. Based on equation (5), the average refractive index for each concentration is summarised in Table 4. This behaviour is depicted in Figure 6. Here we can see that the refractive index depends on the concentration linearly. Denser media have a higher refractive index.

We also found consistently that for the same flask, higher glycerine concentrations caused a decreased in focal length. This observation reveals the dependence of the focal length of a lens on the refractive index as shown in equation (4b). The second term of equation (4b) show that focal length is inversely proportional to refractive index. On the other hand, as mentioned earlier the concentration of glycerine affects the refractive index linearly. Therefore, increasing the concentration of glycerine causes a decrease in the focal length as observed in table 3.

Table 4 shows that the refractive index of glycerine in this experiment is in agreement with the reported publications (İde, C., and Yüksel, 2018). The differences observed at concentrations of 80% and 100% are still within the uncertainty range. The average discrepancy is less than 2%. The difference between our results and the reported values is due to the experimental conditions. The reported values are measured at a specific wavelength, i.e. 589.3 nm, using a special instrument, a refractometer. Our measurements use a simple setup available in the laboratory. In this case, it depends on the visual adjustment. Determination of focus and image relies on visual observation. Therefore, the uncertainty is caused by variations in visual measurement.

Our results are also consistent with other publications. Based on Snell's Law, Ortega et al. (2019) used a low-cost opto-mechatronic educational device to determine the refractive index of water, ethanol, and glycerine. They found that the refractive index of 100% glycerine fluctuated between 1.44 and 1.50, with an average of *n* =1.4675, with a standard deviation of σ = ±0.02. Similarly, using a simple setup, a refractive index of glycerine measured at different temperatures was observed between 1.346 and 1.558 (Chanprasert, 2015).

Table 4. The average refractive index of different glycerine concentrations

No	**Concentration (%)**	**Refractive Index**	**Reported***
1	0	1.33±0.02	1.33300
2	60	1.42±0.03	1.42228
3	80	1.46±0.03	1.44291
4	100	1.49±0.04	1.47332

*) İde, and Yüksel (2018), measured at **589.3 nm**

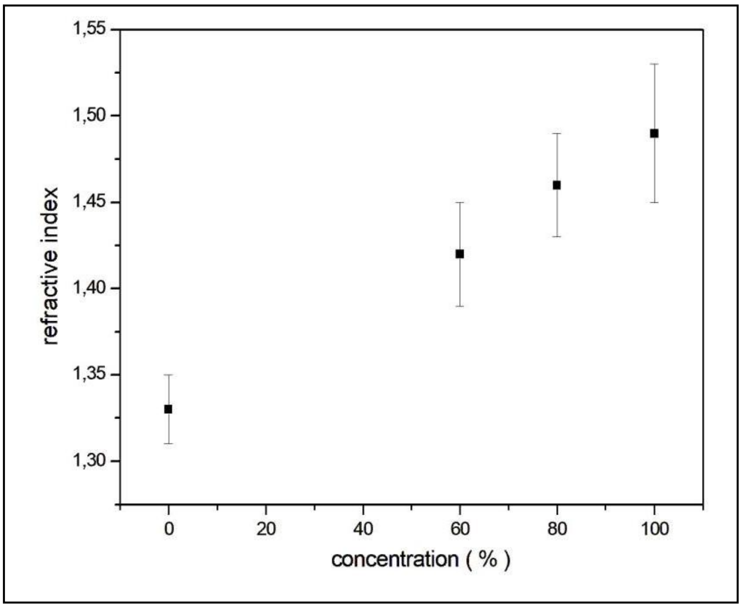

Figure 6. Refractive index for different glycerine concentrations

This experiment is quite simple. Such equipment is available in the most school laboratory. Experiment demonstrates different methods of measurement and data analysis. Therefore, this experiment is suitable for teaching. Here the student can explore the parameters related to the focal length of a lens. Apart from that, they can also apply different experimental method to obtain the focal length and refractive index, as well as a graphical calculation method. The concept of medium-dependent refractive index can be observed easily.

CONCLUSION

The refractive index of glycerine has been determined using a simple setup. The denser glycerine has a higher refractive index. This experiment is based on measuring the focal length of a lens. Various aspects of teaching are featured in this experiment. Students learn the basic concept of physics behind the optical instruments, and perform various methods in experiments.

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