Low Cost DIY Lenses kit For High School Teaching

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Abstract. A set of lenses was fabricated from a low cost materials in a DIY (Do it yourself) process. The purpose was to demonstrate to teachers and students in high schools how to construct lenses by themselves with the local available materials. The lenses could be applied in teaching Physics, about the nature of a lens such as focal length and light rays passing through lenses in either direction, employing a set of simple laser pointers. This instrumental kit was made from a transparent 2 mm thick of acrylic Perspex. It was cut into rectangular pieces with dimensions of 2x15 cm2 and bent into curved shape by a hot air blower on a cylindrical wooden rod with curvature radii of about 3-4.5 cm. Then a pair of these Perspex were formed into a hollow thick lenses with a base supporting platform, so that any appropriate liquids could be filled in. The focal length of the lens was measured from laser beam drawing on a paper. The refractive index, n (n) of a filling liquid could be calculated from the measured focal length (f). The kit was low cost and DIY but was greatly applicable for optics teaching in high school laboratory.

1. Introduction

Physics is a foundation of science, based on experimental observations of the nature around us and presently, expands to observations of everything beyond in the universe [1, 2]. The beauty of physics lies in the simplicity of its fundamental principles in which just a small number of concepts and models can reveal the facts behind these observations [1]. Light is a form of electromagnetic waves which is one of the most common physical phenomena in nature and essential to almost all form of living organisms on Earth [1]. A lens is a transmissive optical device that focuses or disperses a light beam by means of refraction [3-5]. Nowadays smart phone is a common device used by nearly everybody in a modern society. One of the most popular uses is for taking photos and video of anything. This is possible with a set of tiny lens system which is quite complicate for the young generation to understand compared to a conventional camera used in the past. This is a big gap of fundamental science knowledge that they are facing in the digital world.

In this paper, a kind of do it yourself (DIY) [6], simple and easy explanation to follow is described. The purpose is to demonstrate how to fabricate a simple set of lenses and how they can be employed to form image of an object. This DIY kit is suitable for teachers and students in high school. They can explore the basic principle of optics concerning nature of lenses by tracing the rays of light to find out the focal length of a lens. A hollow space inside the lens can also reveal the nature of refraction when light passing through liquid filled in the space. With this kind of activity-based learning (ABL) [7] it is hoped that students will understand the optical principle of lens by themselves experimentally.

2. Lens Fabrication

Low cost DIY (Do It Yourself [6]) lens kit was made from transparent acrylic Perspex sheet 2 mm thick, Figure 1(A(i)). It was cut into a rectangle form with size of 2x15 cm^2 and bent into a cylinder shape employing a cylindrical wooden rod with radius of about 3-4.5 cm and a hot air blower, Figure 1(A(ii-iv)). Then, a lens was formed by a pair of this bent Perspex either as a converging lens, Figure 1(A(v)) and 1(B) or a diverging lens, Figure 1(A(vi)) and 1(C).

3. Lens Learning

Focal length of a lens was determined from a ray tracing of the light beam of a laser pointer on a piece of paper as shown in Figure 1(D) and Figure 2 (A and B). Next, liquid of interest was filled inside the space of the lens, such as Ice (H_2O), water, oil, glycerine and benzene with the liquid index of refraction (n) of 1.31, 1.33, 1.40, 1.47 and 1.50, respectively. It was observed that the focal length of the lens changed due to the refraction nature of the liquid filled inside the lens as shown in Figure 2 (A and B). Then, the refractive index ($\boldsymbol{n}$) of a liquid was calculated from the measured focal length ($\boldsymbol{f}$).

4. Results and Discussion

In this report both converging lens and diverging lens were constructed from Perspex sheet of 2 mm thick. By cutting and bending into a cylindrical shape, a pair of these pieces could be formed into either type of lens. They were used in the optics learning experiment with and without filling liquid and performed clear and easy to understand of the nature of lenses and nature of liquid, as shown in Figure. 1-2(A and B), respectively. We would like to comment here that a cylindrical shape similar to these pieces could also obtained from a clear drinking water bottle but the thickness of the plastic bottle was quite thin that the shape of the lens could be easily deformed. So, more care has to be taken when a lens was constructed from a transparent plastic bottle. From the experiment in the section of lens learning with the arrangement as shown in Figure 1(D) and Figure 2 (A and B). It was a clear and easy to see path of light rays behaved when passing through converging and diverging lens. The rays would converged to a (Focal) point for a converging lens and diverged away for a diverging lens, as shown in Figure 1(D). With a piece of paper, the rays of light from a laser pointer could be easily traced and recorded. By this way the nature of refraction of various kinds of liquid was observed and their refractive indices were evaluated. Although, the diverging lens disperse a parallel light but in this work a converging set of light rays was employed so that a less converging beam was achieved Figure 1(D(IV)) and Figure 2(B)) and refractive index of a liquid could be determined with similar manner. The experimental results for the parallel light traveling through the converging lens and diverging lens are shown in Figure 1(D). The lenses responded differently to the laser beam before and after filling with a liquid. Using a piece of paper, the rays of light from a laser pointer could be easily recorded, as seen in Figure 2 (A and B). By this way the focal length of lenses and the nature of refraction of various kinds of liquid were observed and their refractive indices were evaluated. The liquid used in the experiment were substances that could be found in a high school science teaching laboratory. i.e., Ice (H_2O), water, oil, glycerine and benzene with the liquid refractive index ($\boldsymbol{n}$) of 1.31, 1.33, 1.40, 1.47 and 1.50, respectively. Due to a different refractive index, light wave converged at a different location as shown in Figure 2 (A and B). So that a focal length of the lenses with a filling liquid was determined and the observed refractive index of the substances were calculated as shown in Table 1. By setting the refractive index of air as 1 the calculated results were in good agreement with the standard value, having estimated error of about 1-3 %. In the Figure 2 (A and B), converging lenses that was thin lenses (for a thin lens one whose thickness was small compared with the radii of curvature and we can neglect $\boldsymbol{t}$) can see the inverse of the focal length ($\boldsymbol{f}$) for a thin lens was

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad (1)$$

Consider a lens having an index of refraction ($\boldsymbol{n}$) and two spherical surfaces with radii of curvature $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$. (Notice that $\boldsymbol{R_1}$ was the radius of curvature of the lens surface which the light from the object reaches first and $\boldsymbol{R_2}$ was the radius of curvature of the other surface of the lens [1, 8].) The sign conventions for thin lenses of $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ to be positive when center of curvature was in back of lens and negative when center of curvature was in front of lens. The focal length (***f***) was positive for a converging lens and negative for a diverging lens [1, 8]. The index of refraction of converging lenses experiment ($\boldsymbol{n_{C\text{-}exp}}$) and the index of refraction diverging lenses experiment ($\boldsymbol{n_{D\text{-}exp}}$) of substance was calculated from the equation (1). The results of $\boldsymbol{n_{C\text{-}exp}}$ and $\boldsymbol{n_{D\text{-}exp}}$ were compared with the index of refraction standard ($\boldsymbol{n_{std}}$) have error less than 3% as shown in the Table 1.

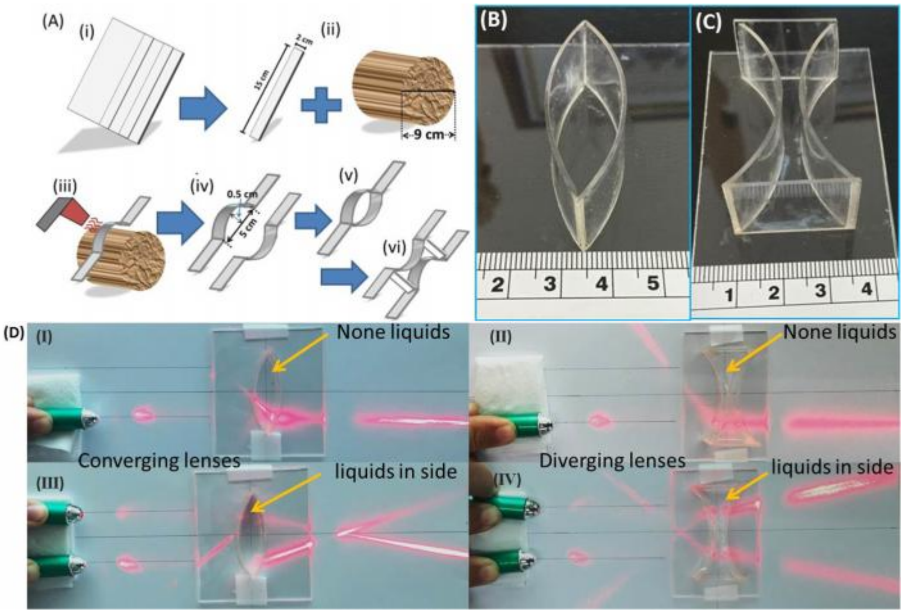

Figure 1. The low cost thin lenses kit was invented by the DIY process from the lens box (A). It was made in a thin lenses form such as converging lenses (B) and diverging lenses (C) that have the air substance in side. Experimental settings up demonstrate the lens learning for converging and diverging lens. (D(I and II)) were for before filling with liquid. (D(III and IV)) were for after filling with liquid. A red light laser pointer of wavelength of 589 nm was employed for the ray tracing.

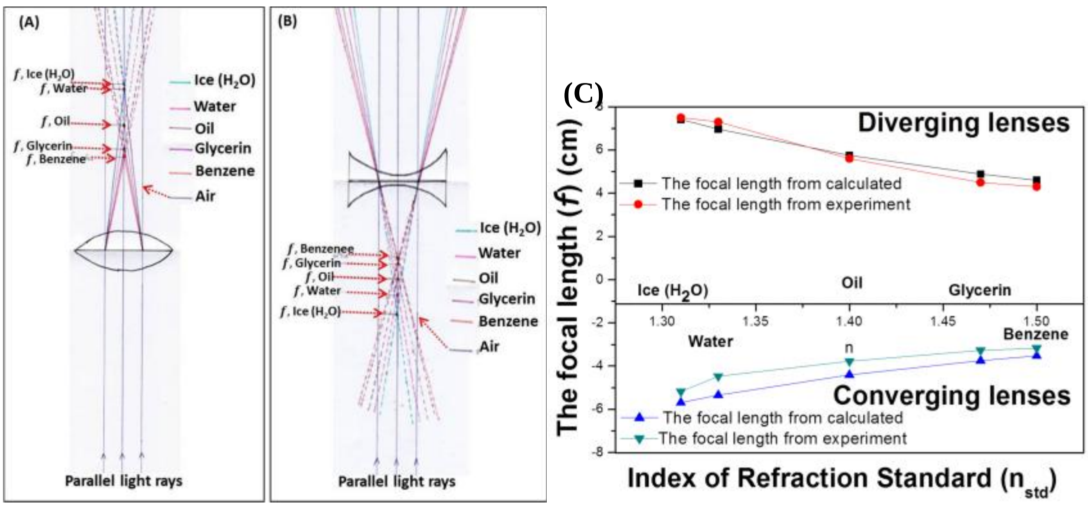

Figure 2. The focus of light laser distance of the converging lenses (A) and the diverging lenses (B) was measured from laser beam drawing on paper. A plot of the focal length of converging lens (C).

Table 1. The index refraction and the focal length of substance.

Substance	Index of Refraction Standard (n_{std}) [A]	Observe Index of Refraction					
		Converging lenses			Diverging lenses		
		The focal length (f) (cm)	Index of Refraction Experiment ($n_{C\text{-}exp}$)	%Error	The focal length (f) (cm)	Index of Refraction Experiment ($n_{D\text{-}exp}$)	%Error
Air	1.00	∞	1.00	0	-∞	1.00	0
Ice (H_2O)	1.31	7.50	1.31	0.26	-5.18	1.34	2.33
Water	1.33	7.3 0	1.32	1.14	-4.48	1.39	4.80
Oil	1.40	5.6 0	1.41	0.76	-3.78	1.47	4.78
Glycerin	1.47	4.5 0	1.51	2.72	-3.28	1.54	4.64
Benzene	1.50	4.3 0	1.53	2.27	-3.18	1.56	3.67

Note: Indexes of Refraction all values are for light having a wavelength of 589 nm in vacuum [1].

The focal length of the converging lens was a positive value because the focal length appeared behind the lens but the f of the diverging lens was a negative value because the focal length appeared in the front of the lens. In Figure 2(C), using equations (1), the values of focal length of the lenses were calculated from the index of refraction of standard substance (n_{std}) and compared with the values of the focal length from the experiment. It was observed that diverging lens gives a more reliable, with less error than the converging lens.

5. Conclusions

Low cost DIY lenses kit for high school teaching was fabricated. Its simplicity was the key for an activity-based learning (ABL) lesson for both teachers and students who lack of expensive equipment but interested in learning about the optical principles of lens. From these kits, a few experiments were carried out to demonstrate how these principles could be realized. Nature of some liquids commonly found in everyday life was also investigated. Further advanced experiments utilizing these kinds of lens kits for daily life applications and SME industrial could be a challenge for them.

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