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# Analyzing The Refraction Of Light On An Object In Water

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**Abstract-** The purpose of this study is to study the phenomenon of light refraction on something in the water. This phenomenon occurs when light passes through the boundary between two media that have different refractive indices, which changes the direction of the light. In this study, experimental methods and mathematical analysis are used to observe changes in the position and shape of the shadow of an object under the water surface. The angle of incidence, the refractive index of water, and the type of material of the object are some of the components that affect refraction that are thoroughly analyzed. The results show that the angle of refraction is proportional to the angle of incidence, in accordance with Snell's law, and the refractive index of water has a significant effect on the deflection of light. In the fields of optics, periscope design, and underwater environmental modeling, this study provides important insights into the optical properties of water.

**Keywords:** *refraction of light, Snell's law, refractive index, underwater optics, refraction*

## 1 Introduction

Education serves as a tool to produce high-quality human resources, Slameto stated that education is an important component in life. To achieve a level of educational success, it is necessary to create a learning environment that supports a student. This must provide support for the teaching and learning process and provide a conducive environment for a student.(Gare et al., 2022).

Mathematical physics is the study of physical phenomena that are studied by using mathematics as a tool or instrument to solve problems. Undoubtedly, the mindset used in learning physics at university is still difficult for some students to understand, so creative methods or approaches are needed to understand mathematical physics. For example, by providing a visualization of a mathematical equation that has high artistic and aesthetic value, it will increase students' curiosity and interest in seeing physical phenomena from a mathematical and artistic perspective. It is hoped that as a result of studying mathematical physics, students will be able to explain abstract phenomena(Ermawaty, 2018)

Physics lessons help students analyze something. In addition, physics education teaches students about the universe, helps them think and reason, improves their reasoning skills, and improves their thinking power. Physical learning should be evaluated because of its importance in the process of analyzing something. Learning is a system that relates to elements of analyzing material, evaluation, and learning methods. Therefore, learning modules can be used to guide the learning process. The learning method in implementing good physical education and supported by a creative and innovative student in understanding physical education can be used in this learning approach to analyze problems. The motivation given by a student is very useful in the learning process, which will be very popular with many people.(Gare et al., 2022)

There are many theories about physical learning that have been put forward by famous scientists. For example, Christiaan Huygens, a Dutch scientist who created a wave theory model of light in 1678. He

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theorized that waves are formed from light emitted from a source in all directions. Experiments by analyzing light waves are usually done to find out the angles or high and low levels of waves and the length of the

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waves produced. This uses the same light interference measurements used to measure and capture light waves produced by experiments(Suhadi, 2019).

The term "light wave" refers to the processes of reflection, refraction, diffraction, interference, and polarization of light. The bending of the direction of light propagation due to its density through different media is called refraction. When light waves hit a smooth interface separating two transparent (translucent) materials, such as air and water, or water and glass, most of the wave is reflected and some is reflected within the two materials. Refraction is a physical phenomenon that is beneficial to life. The difference in density of the media as light passes through them causes the bending of light to occur. The refractive index refers to the ratio of the speed of light in a substance to the speed of light in a vacuum. The refractive index of a substance is measured by calculating the speed of light in the liquid compared to when the substance is in air.(Suhadi, 2019).

The event when the direction of light propagation changes from one medium to another is called refraction. The value of refraction or deflection of the direction of light propagation that comes out of a medium depends on its optical density. Optical density is the property of a translucent medium (optical substance) in passing light. If light enters from a denser optical substance (air to water) to a denser optical substance (glass to air), the light will be refracted approaching the normal line. The normal line is a line perpendicular to the boundary plane of the medium(Suhadi, 2019).

According to Huygens' principle, every point on the wavefront can be considered as a source of secondary waves. The primary wave travels at the same speed as these secondary waves. At a later time, a new wave unites all these secondary waves. When light waves hit a gap or obstacle, this principle helps us understand how they propagate, bend, and refract. Phenomena such as diffraction and interference of waves are also explained by Huygens' theory.(Sinaga & Ngaderman, 2022)

The purpose of taking the title "Analyzing the Refraction of Light on an Object in Water" is to understand how When light passes through the boundary between two mediums with different refractive indices, such as air and water, the light experiences a deflection of direction, which makes the object in the water appear to be in a different place than it actually is. This is known as the refraction of light. For example, if you put a pencil in a glass of water, the surface of the water will look like there are pieces in it. Snell's Law explains this phenomenon. It shows the relationship between the angle of incidence, the angle of refraction, and the refractive index of the two media. Understanding the refraction of light has many practical applications. These include the use of optical instruments, lens making, and diving. We can understand how light interacts with various mediums by studying the refraction of light. We can use this knowledge in everyday life(Zamroni, 2013).

## 2 Research Methodology

The type of research used is descriptive. Descriptive research is research that provides an overview of a situation, problem, phenomenon, service, or plan, or provides information about the conditions and conditions of people's lives, attitudes, opinions, and life processes, as well as careful measurements of social phenomena. Researchers usually conceptualize and collect data, but they do not test hypotheses. Kaelan (2012), pp. 12–13. The data collected for descriptive research consists of text, words, symbols, and images. Therefore, to explain the delivery of the report, the research report will contain data excerpts(Li et al., 2024).

Researchers use descriptive qualitative research methodology. Researchers use literature research methods to collect and analyze data from various published journals. To collect data, researchers use literature study data collection methods to collect relevant or relevant data for research from scientific articles, news, and other reliable sources. The collected data are analyzed using qualitative descriptive methods. To produce good results, researchers collect data from journals and other sources that are reliable and factual.(Mukhlis et al., 2021). Using experimental methods to quantitatively analyze the refraction of light on objects in water. A transparent object, such as an acrylic block, is inserted into a container of water. A laser beam is directed at the object at various angles. To determine the relative refractive index between the water and the object, a goniometer is used to measure the refractive angle of the laser beam as it exits the object. The incident angle data is then analyzed using Snell's law(Anbu Serene Raj et al., 2024).

In addition, optical simulation software is also used to ensure that the experimental results are correct. The theoretical approach begins with the creation of a mathematical model that describes the propagation of light in a multi-medium system.(Li et al., 2024). This model is based on the laws of optical physics such as Snell's law and Fermat's principle, and then solved numerically using simulation software. To validate the model and gain a better understanding of the light refraction phenomenon, the simulation results are compared with experimental data.(HU et al., 2022).

## 3. Results and Discussion

The most common phenomenon is the refraction of light, but refraction also occurs in other waves such as sound and water. Refraction of light makes it easier for light to be directed to the retina, which allows the use of optical instruments such as lenses, prisms, and magnifying glasses. Refraction occurs because of changes in speed that change direction. When a ray of light moves into a medium with a different refractive index at an angle, its refraction changes. For example, let's look at how air flows gently into water. As light moves at a different angle, the speed of light begins to slow down.(Siahaan et al., 2020).

One of the most important optical properties of a medium is the refractive index, which is measured by measuring the speed of light in the liquid compared to the speed of light in air. The refractive index of a medium is usually defined as the ratio of the speed of light in a vacuum to the speed of light in the medium.(Malik et al., 2021)

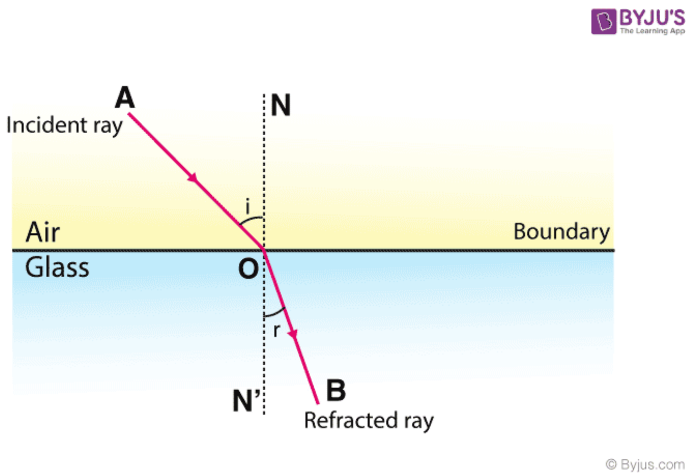


Figure 1

Figure 1 shows the refraction of light. Light slows down and crosses its path slightly as it moves from air to glass. When light moves from a less dense substance to a denser substance, the refracted light bends closer to the line of refraction. There is no refraction of light when the light waves move perpendicularly toward the boundary.

According to the law of refraction, the incident light, the incident light, and the normal to the intersection of the two media at the point of contact all lie in a uniform plane. The incident sine and the normal sine do not change. Another name for this is Snell's law of refraction.(Sun & Kim, 2004).

A deep understanding of the refraction of light is demonstrated in the history of Snell's law. One of the most important laws of optics is Snell's law, which describes the relationship between the angle of incidence and the angle of refraction when light travels through a boundary between two media. For example, when light travels through air and water, or when light travels through air and glass. This law is named after the Dutch scientist Willebrord Snellius, who is credited with discovering it.(Vorsanger, 2024).

The basic principle of this law was actually known and studied by scientists before Snellius, although it was named after Snellius. Important figures before Snellius included Ibn Sahl, an Arab scientist from the 10th century who formulated a law of refraction very similar to Snell's law. To improve vision, he created lenses using this idea. English scientist Thomas Harriot studied the refraction of light in the early 17th century, and his findings were in line with Snell's law.(Durach, 2024).

During the 17th century, Snell was an active scientist who conducted more structured research on the refraction of light. He conducted many experiments and managed to transform the law of refraction into a more precise mathematical formula. However, Snell's findings were not widely published. After Snellius, the French philosopher and mathematician René Descartes independently formulated the law of refraction and published it in his work entitled "Dioptrics". As Descartes became more famous, this law of refraction is often referred to as "Descartes' Law". French mathematician Pierre de Fermat explained Snell's law theoretically based on the principle of minimal travel time. The understanding of various optical phenomena depends on Snell's law. The image produced by lenses and mirrorsThe refraction of light in the atmosphere. Snell's law forms the basis for modern optical advances such as fiber optic technology and metamaterials. It also shapes the way various optical instruments such as cameras, telescopes, and microscopes work(Vorsanger, 2024).

All refraction calculations depend on Snell's law. This law states that the ratio of the sine of the angle of incidence (i) to the sine of the angle of refraction (r) is equal to the ratio of the refractive indices of the two media. Mathematically, Snell's law can be written as(Li et al., 2024):

$$\frac{\sin i}{\sin r} = \frac{n^2}{n^1} \tag{1}$$

Where:

i = angle of incidence
r = angle of refraction
$n_1$= refractive index of the first medium (e.g., air)
$n_2$= refractive index of the second medium (e.g., glass)
Refractive Index

The refractive index (n) is the ratio between the speed of light in a vacuum (c) and the speed of light in a medium (v).

$$n = \frac{c}{v} \tag{2}$$

The greater the refractive index of a medium, the slower light travels through it, and the greater the bending of light as it passes through the medium.

Snell's law of refraction

$$n_1 \ sin\ i = n_2 sin\ r \tag{3}$$

Where i is the angle of incidence and r is the angle of refraction.

$$r_1 + r_2 = A \tag{4}$$
$$\delta = \ (i_1 - r_1)\ + (i_2\ -\ r_2)\ = i_1 +\ \mathbf{i}$$

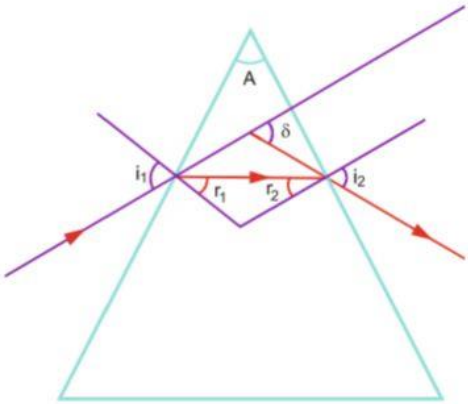


Figure 2

For minimum deviation angle

$$\delta = D, i_1 = i_{2,} \, r_1 = r_2$$

$$n = \frac{\sin\frac{1}{2}(A + D)}{\sin\frac{1}{2}(A)} \qquad \textbf{(5)}$$

If a prism of index n is placed in a medium of index 12 then a must be replaced by $n._1/n_2$.
Lens: Object distance (u), image distance (v) and focal length (f)

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad \textbf{(6)}$$

The Lens Convention is formulated:

$$\frac{1}{F} = (\text{n }) (\,) - 1 \frac{1}{r^1} - \frac{1}{r^2} \qquad \textbf{(7)}$$

r has a positive value if the refractive surface facing the object is convex and r has a negative value if the refractive surface facing the object is convex.

If $v_2$positive then the image is real, if uz is negative then the image is virtual.
System matrix

**l2= R21 T2 R12 11** **(8)**

So the initial image 11 in medium 1 is changed to the final image 12 in medium 2. $R_{12}$is the refraction matrix on the first surface (air to glass), 72 is the translation matrix on the second medium (glass) and $R_{12}$is the refractive matrix on the second surface (glass to air).

The distance from the camera to the refractive interface, the normal refractive direction of the interface, and the refractive index of different media are the refractive parameters included in the above measurement model. The measurement results may be affected by the calibration error of these parameters. Therefore, the effect of the deviation of the refractive parameters on the measurement results should be investigated. Conducting such an evaluation through underwater experiments is somewhat difficult, but experimental simulation is more efficient.(Malik et al., 2021).

Therefore, this paper investigates a simulation model for underwater stereo-visual measurement. For simplicity, the camera is placed in the air and the target is in the water, which is an air-water scenario. Taking

the left camera coordinate system as the reference coordinate system. Given that the target coordinate P is ($x_1$, $y_1$, $z_1$); the distance of the left camera to the bias interface is D, and the normal vector of the bias interface is N. The camera is in the air.
The target is in the water. The refractive indices of air and water are n respectively.$_1$and $n_2$(Kamal, 2011).

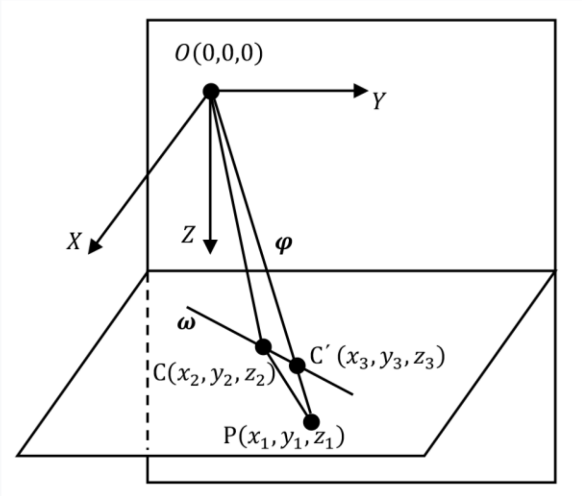


Figure 3

The direction vector φ of line OP is

$$\varphi = \boldsymbol{P} - \boldsymbol{O} \tag{9}$$

All refracted PC-CO light is in the refractive plane. Since PC and CO are coplanar with the normal vector N of the refractive interface, the normal vector of the refractive plane is

$$\boldsymbol{x} = \frac{\boldsymbol{\varphi} \times \boldsymbol{N}}{\|\boldsymbol{\varphi} \times \boldsymbol{N}\|} = [\boldsymbol{x_1} \;\; \boldsymbol{x_2} \;\; \boldsymbol{x_3}] \tag{10}$$

Where × denotes the cross product. The unit normal vector of the intersection CC' of the refractive plane and its refractive interface.

$$\boldsymbol{\omega} = \frac{\boldsymbol{X} \times \boldsymbol{N}}{\|\boldsymbol{X} \times \boldsymbol{N}\|} = [\boldsymbol{\omega_1} \;\; \boldsymbol{\omega_2} \;\; \boldsymbol{\omega_3}] \tag{11}$$

Determine the coordinates of a point on the line CC' which is denoted by (x0, y0, z0). Then, the line CC' can be expressed as

$$\begin{cases} \boldsymbol{x} = \boldsymbol{x_0} + \boldsymbol{\lambda\omega_1} \\ \boldsymbol{y} = \boldsymbol{y_0} + \boldsymbol{\lambda\omega_2} \\ \boldsymbol{z} = \boldsymbol{z_0} + \boldsymbol{\lambda\omega_3} \end{cases} \tag{12}$$

According to the relationship between refractive index and speed of light, if the speed of light in a vacuum is c, the speed of light in air and water is

$$\begin{cases} \boldsymbol{v_a} = \dfrac{\boldsymbol{c}}{\boldsymbol{n_1}} \\ \boldsymbol{v_w} = \dfrac{\boldsymbol{c}}{\boldsymbol{n_2}} \end{cases} \tag{13}$$

Suppose the coordinates of point C are (x2, y2, z2). The lengths of the two optical paths OC and CP are

$$\begin{cases} \iota_{OC} = \sqrt{x\frac{2}{2} + y\frac{2}{2} + z\frac{2}{2}} \\ l_{CP} = \sqrt{(x1 - x2)^2 + (y1 - y2)^2 + (z1 - z2)^2} \end{cases} \quad (14)$$

According to the relationship between speed, time, and distance, the propagation time of light between O and P is

$$t = \frac{l_{OC}}{v_a} + \frac{l_{CP}}{v_w} \quad (15)$$

When all refraction parameters are known, it is a function of the coefficient λ. According to Fermat's Principle, the actual path of light passing through two fixed points in space is always the shortest optical path (or propagation time). Thus, the derivative of t is equal to 0, i.e.

$$f(\lambda) = \frac{dt}{d\lambda} = 0 \quad (16)$$

By solving the above formula, we can get the value of λ. Combining it with the above Equation, the coordinates of point C can be obtained. So, the complete light propagation path is the right camera, the simulation process is almost the same, the only difference is that lOC is transformed into the following form:

$$l_{OC} = \sqrt{(x_R - x_2)^2 + (y_R - y_2)^2 + (z_R - z_2)^2} \quad (17)$$

Where (xR, yR, zR) are the coordinates of the origin point of the right camera coordinate system in the reference coordinate system. The target pixel coordinates can be easily calculated based on the coordinates of point C and camera parameters using the perspective imaging model, thus realizing the simulation of the imaging process.

## 4. Conclusion

The article "Analyzing the Refraction of Light on an Object in Water" explains the phenomenon of refraction of light that occurs when light travels through two mediums with different refractive indices, such as from air to water. This process changes the direction of the light, which makes the object in the water appear closer or have a different shape. Snell's Law, which relates the angle of incidence, angle of refraction, and refractive index of the two media, explains this phenomenon. In addition, this article discusses refraction variables such as the angle of incidence of light and the differences in refractive indices of the media. Readers also gain a better understanding of the importance of refraction in everyday life through examples of everyday applications, such as making a straw appear broken in a glass of water. This article provides scientific information about the refraction of light and how it affects the way objects in water are seen by people.

The phenomenon of refraction of light occurs when light travels through two mediums with different refractive indices, such as water and air. This process changes the direction of the light, making things in the water appear closer or have a different shape. Everyday examples of applications, such as creating the illusion that a straw is broken in a glass of water, help readers understand the importance of refraction in life.

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