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WIP: Teaching Physics Through a Medical Lens

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Teaching Physics Through a Medical Lens

Abstract:

Physics generally falls under engineering programs yet is required for a multitude of different majors spanning many departments and disciplines including medicine. When people think about the medical field, their mind immediately goes to classes such as biology, chemistry, anatomy and physiology. However, when looking at the prerequisite courses for medical school or tested MCAT content, there seems to be one subject that doesn't fit in with the rest: physics. For years, pre-health students have joked that physics is much less applicable to their future careers than the other courses. The goal of this research paper is to tackle the general student assumption that understanding physics will not help them in their respective fields by providing real-life examples of physics principles being used. The text will be split into subsections based on the first unit of an "Introductory Physics II" course, which covers topics such as lenses, parallax, reflection, refraction and vision. The paper is meant to supplement course content and lesson objectives. The paper aims to approach the applications from a student point-of-view and present information in a compelling and digestible manner such that it can be understood by members of a variety of disciplines. The paper is being written to honorize the introductory physics II course and to further passion for the medical field through physics.

Light: An Introduction

Visible light has been the subject of research and theories for centuries. Many of the observations and conclusions about light can be summarized in one central statement: light will travel in straight lines unless interrupted by an outside object. In the 3rd century BCE, the Greek mathematician Euclid developed the **law of reflection**, which stated that light travels in straight lines, and will reflect off a surface at the same angle the light hits the surface with. Later in the 17th century, it was discovered that light could also **refract,** meaning it bent when entering a new medium [1]. Studying such tendencies of light can help us better understand the world around us and how we perceive our environment. For example, the law of reflection served as the basis of many concepts in physics, such as shadows, mirrors and pinhole cameras. This paper aims to examine these physics topics through a medical lens first by discussing the anatomy of the eye and its relation to pinhole cameras. The paper will then continue by explaining various medical conditions with the properties of light and their solutions. Finally, the paper will conclude with a discussion of medical devices that utilize properties of light, including head mirrors and sunscreen.

The Human Eye: The Organ Behind the Most Dominant Sense in Humans

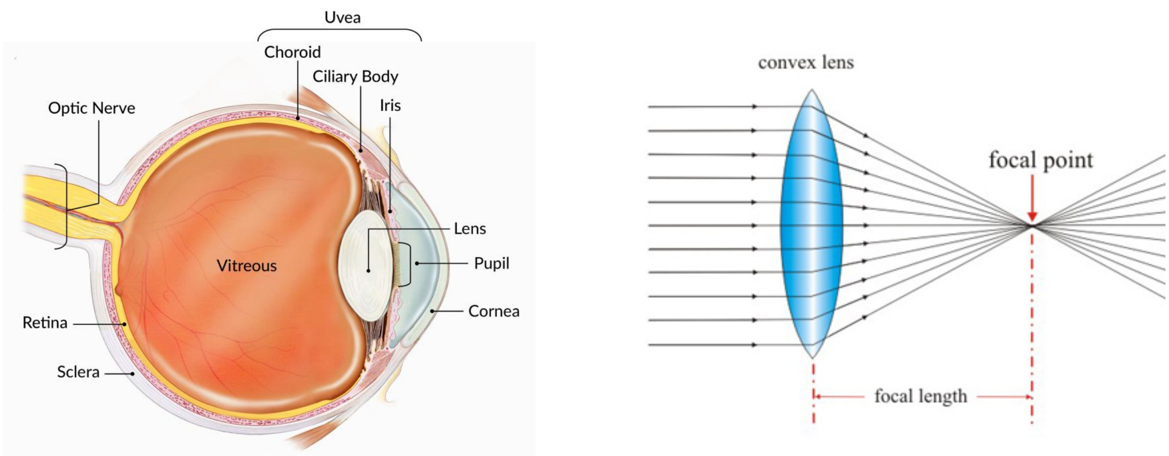

Fig.1 The image on the left shows the anatomy of the human eye, and the image on the right shows the refraction of light rays to a focal point in a convex lens. [1]

The science behind the eye is miraculous. Nearly 70% of the sensory receptors in the body are located in the eyes. These receptors are located in the back of the eye, called the **retina** [1]**.** It is a combination of these receptors as well as the shape of the eye that allows us to see. The front of the eyeball, known as the **cornea**, is transparent and takes the shape of a **convex lens**, a type of transparent lens that refracts all incoming light rays into one point. The light is being refracted as it originates in one medium (air) and enters a different medium (the cornea). The anatomy of the eye is shown in figure 1. **Snell's law** can be used to approximate how much incoming light rays will refract when entering the cornea as shown in figure 1.

$$n_1*\sin(\theta_1) = n_2*\sin(\theta_2) \quad (1)$$

In equation (1), theta is the angle measured from the line normal to the surface and the variable "n" is the index of refraction. Air has an index of refraction of approximately 1.00, while the cornea has been experimentally found to have an index of refraction of 1.376[2]. Using Snell's law, it can be determined that when going from a medium of lower index of refraction to one of a higher index of refraction, light will refract away from the normal line. Referring to the diagram above of a convex lens, this prediction matches the observation, as light rays will exit the cornea in a straight line angled further from the normal line.

The **iris** is made up of muscle tissue and controls the amount of light that is let into the eye through the **pupil**. This portion of the eye is comparable to a pinhole camera, a type of camera that produces inverted images but is mainly used for its infinite **depth of field**, a term used to describe the range of distances that an object can be in and remain clear [3]. An ideal pinhole camera has a hole that allows only one ray of light through producing a sharp image; enlarging the size of the hole will lead to a more blurred image. Similar to a pinhole camera, shrinking the entrance point for light rays in the eye ensures that the light is less scattered. Thus, the smaller the size of the pupil, the sharper the image the brain perceives will be. When in bright environments, the iris will shrink the size of the pupil, allowing fewer light rays through and sharper images. In dark environments, the iris dilates the pupils, sacrificing sharpness in order to let more light in and make objects brighter and more visible.

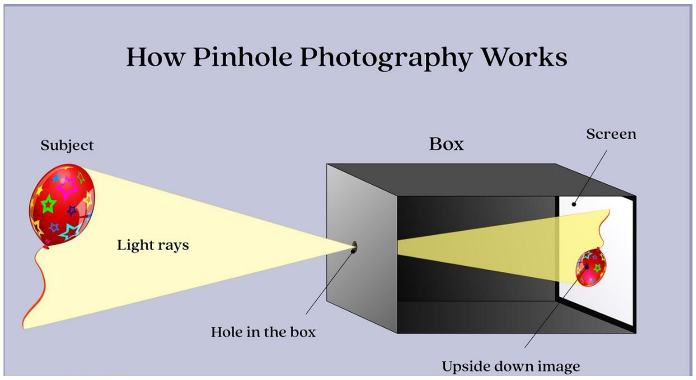

Fig.2 The image demonstrates the setup and image formation by a pin hole camera. [3]

After hitting the cornea and refracting through the pupil, the refracted light hits the **lens**, which further focuses the incoming light rays into one location on the photosensitive retina known as the **focal point**. As seen in figure 2, the pinhole camera produces an inverted image on its screen. They sensory image in the eye also ends up inverted. We can see the world around us right-side up due to the eye’s connection with the brain via the optic nerve, which corrects the image!

In addition to the eye itself, certain glands around the eye can aid in the clarity of what we see. The **lacrimal glands** located above the eye and below the eyebrow supply the eye with tear fluid, a liquid mixture of water, oil and mucus [4]. The index of refraction of the tear-cornea complex is around 1.423[3]. This tear film slightly refracts light, allowing for a better focused focal point, and thus, better vision. It can reduce the scattering of light and any irregularities on the surface of the cornea, providing a smooth lens for light to refract. Those with poor tear production are known to have **ATD, or Aqueous Tear Deficiency;** as expected, ATD is associated with photosensitivity as well as overall blurred vision [5]. A study using the Schirmer's test, a test used to see how many tears an eye produces, confirmed that participants with ATD showed much lower scores on the Schirmer's test and significantly worse vision, confirming the physics behind the diagnosis [4].

How Can Vision Go Bad?

Just as physics can explain how the eye works, it can also give insight into the eye's 'errors.' As described earlier, the convex shape of the cornea and the lens are crucial to the proper refraction of light. Consequently, any alteration to the convex shape can cause **refractive errors,** which are problems with the eye that reduce the sharpness of vision [6]. For vision to be clear, the **focal point** of the refracted light must lay on the retina. Refractive errors cause the focal point to be either in front or behind the retina.

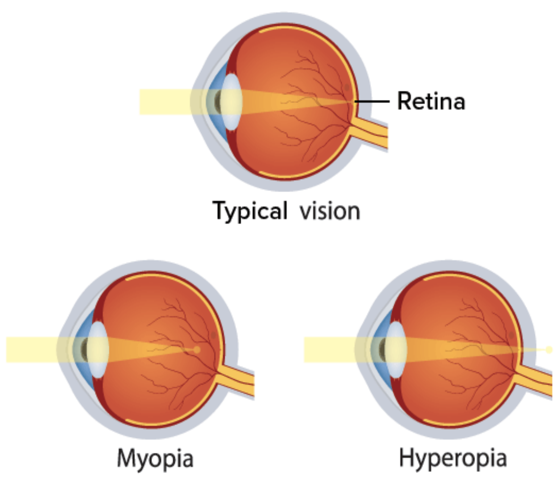

Fig.3 The figure shows the location of the focal points for typical, myopic, and hyperopic eyeballs. [1]

Natural neonatal refractive errors are common, but as long as postnatal development is normal, these issues will reduce over time in a process known as **emmetropization** [7]**.** When postnatal development is disturbed, refractive errors persist. According to the National Institute of Health, over 150 million Americans have such issues [1]. Typical refractive are shown in figure 3. And discussed below.

Myopia (Nearsightedness)

People who are myopic have trouble seeing objects in the distance. Unlike pinhole cameras that have an infinite depth of field, converging lenses such as the eye can only focus on one object at a time. This is where the **focal point** is. Myopia is primarily due to the eyeball being too long, causing the cornea to be too curved and the **focal point** to be in front of the retina [7]; the more curved the lens, the shorter the distance of the focal point. Thus, the photosensitive receptors on the retina are not activated as easily, making it difficult for the brain to capture a clear image.

Myopic people use diverging lenses to effectively increase the focal length of the cornea, pushing the created image back to the retina. Higher power diverging lenses are needed to correct for more severe cases of myopia.

Connecting back to pinhole cameras, optometrists can use pinhole occluders to temporarily remove the effects of myopia by allowing the eye to have an infinite depth of field. Other treatments for myopic control include low-dose **atropine**, which has been reported to increase extracellular matrix creation in the eye, thus reducing elongation of the eyeball over time [7]. However, for our concerns, let's focus on lenses.

In physics, we can use the lens equation to understand this phenomenon. The equation relates the focal length of a lens (f) to the object distance (do) and the image distance (di)

$$1/f = 1/do + 1/di \qquad (2)$$

As an example problem, consider a myopic person who is trying to focus on an object that is 75 cm in the distance. What is the focal length of the lens needed to produce an image that is 25 cm away from the eye?

$$\mathbf{1/f = 1/do + 1/di}$$
$$(1/f) = (1/75\ \text{cm}) + (1/\text{-}25\ \text{cm}) \qquad (3)$$
$$f = \mathbf{-37.5\ cm}$$

The focal point being negative is an indication that a diverging lens would be needed to fix the nearsightedness. The image distance is negative as the image is virtual. Calculating the focal point can also allow for the power (in diopters) of the lens to be calculated. This is what is typically seen on packaging for glasses.

$$\mathbf{P = 1/f}$$
$$P = (1/\text{-}0.375\ \text{m}) \qquad (4)$$
$$P = \mathbf{-2.67D}$$

Hyperopia (Farsightedness)

Hyperopia, or farsightedness, is the most common refractive error amongst children. In fact, most humans are hyperopic at birth but grow emmetropic in postnatal development. If untreated, hyperopia can develop into **amblyopia**, also known as lazy eye [8]. Those that are hyperopic have trouble seeing objects that are nearby. Hyperopia is due to the eyeball being too short, causing the cornea to be too flat and the **focal point** to be behind the retina and again making it difficult to see the world around them [7]. Hyperopic people use converging lenses to effectively decrease the focal length of the cornea, pushing the created image forward to the retina.

Example: Again, we can use the lens equation to understand this phenomenon. The variables are the same, with focal length of a lens (f) relating to the object distance (do) and the image distance (di). Consider a hyperopic person trying to read a book near their eye. They wear contact lenses with refractive power of +5D. The image produced by the contact lens is approximately 35 cm away from their eye. How far must the text of the book be from their eye for the image to appear at this distance?

$$\mathbf{P = 1/f}$$
$$+5D = 1/f \qquad (5)$$
$$f = 0.2\ \text{m} = \mathbf{20\ cm}$$

$$\mathbf{1/f = 1/do + 1/di}$$

$$(1/20 \text{ cm}) = 1/do + (1/35 \text{ cm}) \qquad (6)$$

$$do = \mathbf{46.7\ cm}$$

Astigmatism

Despite being one of the most common refractive errors in humans, research has yet come to a conclusion about the anatomical causes behind astigmatism [9]. However, it is widely understood that astigmatism stems from bright lights that are refracted differently by the eye, typically causing two focal points and a streaky look to strong lights. In physics, it is said that this is caused by the different refracting powers of different parts of the eye. Research has shown that astigmatism is passively correlated with induced and natural changes in eyeball length [9]. This is possibly due to the strong evidence that astigmatism alters **emmetropization.** As expected, astigmatism can be fixed with smoothly curved lenses that mask the uneven shape of the cornea [9]. This way, light can be properly refracted and only one focal point is produced on the retina.

LASIK

One common procedure done for those who do not want glasses or contacts is LASIK, a procedure that uses lasers to permanently alter the shape of the cornea to fix **axial ametropia**, a general term encompassing both myopic and hyperopic issues [10]. The procedure begins by removing a flap of epithelial tissue from the eye. Then, an ultraviolet light laser is used to reshape the eye. For myopic patients, the laser is used to flatten out the overly curved cornea while in hyperopic patients, the laser is used to add curvature to the overly flat cornea. LASIK can also be used to treat astigmatism, by evening out the surface of the cornea.

Mirrors and Light Reflection: Head Mirrors as an application tool in Medicine

Remaining one of the oldest and most iconic tools still used in practice today, the head mirror cleverly uses many physics principles to examine the ear, nose, and throat. Though preceded by many other designs, Friedrich Hoffman is the first one to be credited with describing what is known now as the modern head mirror, a concave mirror with a hole in the center. Typical head mirrors have a focal length of about 23 centimeters, meaning that using a head mirror at this distance from the patient is most effective [11]. Head mirrors are typically paired with a light source placed beside the patient, allowing the light to reflect off the mirror and at the desired location, typically on the ear, nose or throat. The hole in the middle of the mirror allows for both eyes to see the patient and the reflected light, eliminating the problem of parallax [11].

Conclusion:

As illuminated throughout the paper, many medical topics can be explained using physics concepts. The goal of this paper was to provide additional resources for students to supplement learning by putting concepts into medical contexts. Writing the paper has been eye-opening to further solidify conceptual ideas in a field of interest and passion as learning is strengthened by thinking about topics through many lenses. It is hoped that this paper can help explain concepts about light, reflection, and refraction to other students, and demonstrate physics' relation to medicine.

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