A Water Model of a Human Eye

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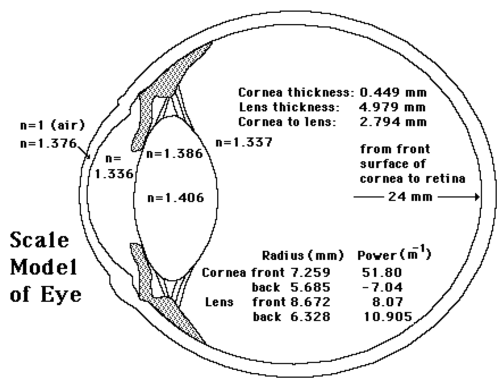
Abstract

The phenomenon of refraction is usually demonstrated with lenses. But very seldom it is properly stressed, that only the change in refractive index is needed for refraction to occur. As a consequence, it is a common belief that only lenses made of special optical glass or optical instruments have the ability to refract the light.
Water lenses are nearly as effective and a very welcome change for the classroom, either as a motivation, as a demonstration to overcome the above mentioned misconception, or as a mind teaser at the end of the lecture. They also offer the possibility of interdisciplinary approach. Using various water lenses it is easy to demonstrate how a human eye works. Experiments modeling eye–lens accommodation, which provides sharp images of near and distant objects, as well as a human eye model, with possibility to visualize vision within healthy and defective eyes, will be demonstrated.

Human Eye Optics

Human eye is a very adaptable and capable optical device. It can provide sharp images of near and very distant objects, in various light conditions. Adequately, its structure is very complicated. Its properties can be seen in Picture 1.

Picture 1: Human Eye properties. (http://hyperphysics.phy-astr.gsu.edu; numerical data from E. Hecht: Optics)



Eye as a whole is a convex optical device, projecting a small, real and inverted image of the surroundings on the retina. Light enters into the eye through the cornea, a transparent membrane which covers the front surface of the eye, passes through aqueous humor and through the opening in the iris, proceeds through lens and vitreous humor, and is finally absorbed in the retina, covering the inner surface of the eyeball at the back.
Majority of the refraction (about 80%), contributing to the formation of the sharp image on the retina, happens in the cornea, since the change of the refraction index (from 1 in the air, to 1,376 in the cornea) is greatest there. Substantial bending again occurs as the light enters the lens, but only about 20% of the total effect happens there. But the lens is pliable and fine focusing and accommodation, which provide sharp images of near and distant objects, happen there and only there.

Accommodation

When the eye rests, the muscles, holding the lens into position, are relaxed, the lens is flattened, the radii and the focal length being greatest. The image of the distant objects is sharp on the retina. When we look at the near object, the muscles contract and the lens is forced into more rounded shape. Its radii and the focal length decrease, providing sharp image of the objects within small distance. This function is crucial for focusing, since the size of the eye and the distance between the lens and the retina is constant.

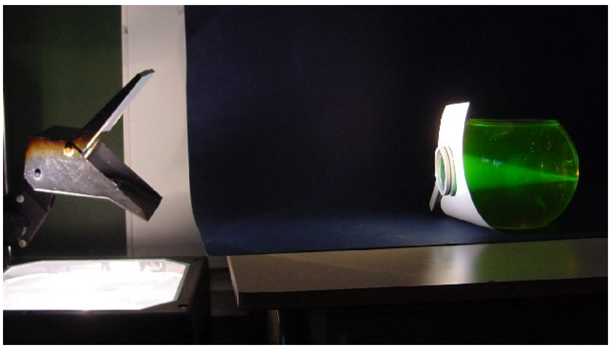
Malfunctioning Eye

We will focus on two most common and interesting dysfunctions from the optical point of view, nearsightedness and farsightedness. It happens very often, that the sharp image of the object does not fall on the back of eye, the retina. Sometimes it is the shape of the eye, which prevents the forming of the sharp image, and, mostly with aging, sometimes the lens becomes too rigid to accommodate adequately.
Some people can see clearly only the objects within short distances, but not the distant ones. It is called nearsightedness and it happens when the parallel rays from distant objects are focused in front of retina. Glasses with concave lenses help, diverging the rays slightly.
Farsightedness is called the situation, when the rays from the nearby objects are bent insufficiently, and consequently focus behind the retina. The person sees them blurred, while distant ones are clear. Placing a convex lens in front of the eye helps with additional bending of the rays.

Human Eye Model

A questionnaire, given to a first year students at the faculty revealed, that nearly one half of the students has no idea how the light propagates through the eye and how the image is formed. This stimulated us to design a simple model of the eye, as shown on picture 2.

Picture 2: Water model of a human eye. Photo by G. Iskric.



Water model of the eye consists from a semi spherical fish bowl, filled with slightly colored water to make the light ray visible. (A drop of milk in the water also works well.) A piece of cardboard with round hole is added in front to represent the iris. A set of three convex lenses with appropriate focal lengths (depending on the size of the fish bowl) is used to represent cornea and lens together, one for each of normal, nearsighted and farsighted eye. Additional convex and concave lenses are used as “spectacles” to correct the vision. Overhead projector serves as a light source (object). Picture 3 shows the model, featuring farsighted (left) and nearsighted (right) eye.

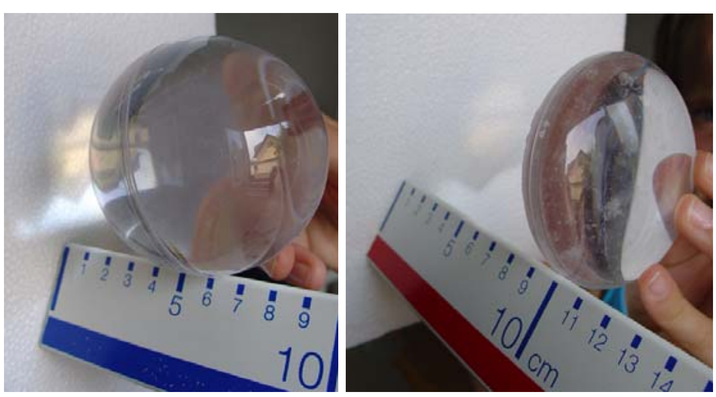
Picture 3: Water model of farsighted (left) and nearsighted (right) eye. Photo by G. Iskric.

Modeling Accommodation

Human eye lens provides sharp images of near or distant object (but not simultaneously) by changing the radii. This is necessary because the distance between the lens and retina is constant. It is very important to stress this to the pupils, and perform some experiments demonstrating that before the demonstration of the model.
Two transparent Christmas tree decoration spheres (commonly available at art shops) with different radii and filled with water (which has a refractive index close to that of the cornea and lens) are used to model the lens. A ruler to control the distance, light source (a candle serves well) and a piece of white cardboard for a screen (a retina, actually) are other things we need.
To get the best results, water should be prepared at least a day in advance, allowing the dissolved gasses to escape. Otherwise gas bubbles form on the wall inside the sphere and disperse the light. (This we can use to model cataract, another eye disease.) Sphere is filled with water simply by immersing it completely underwater and closing it there.
When looking at distant objects the eye lens is flat, so we use the flattened sphere to model it. With older students, the radii can be measured and the focal distance calculated. A connection with the diopter, a measure of the correcting power of the eye glasses can also be discussed. With younger students the focal length is simply measured as a distance between the lens and the screen with sharp image of distant objects projected on the screen (see Picture 4).

Picture 4: Lens with smaller radii (a) also has a shorter focal distance than the other (b).

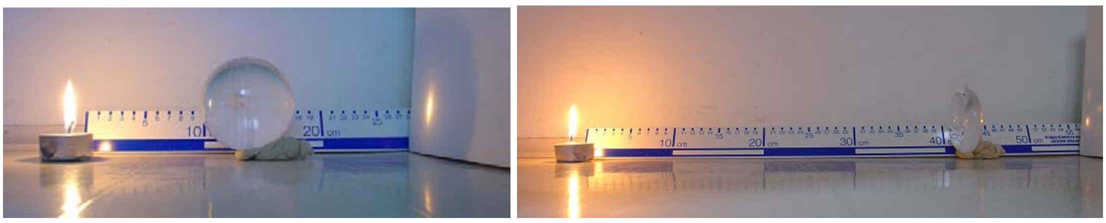
a) b)



If the distance between the lens and the screen is kept constant, we expect that the lens with smaller radii provides a sharp image of a nearby object, as it bends light rays more effectively as the flat one. The other one, on the contrary, provides a sharp image of a distant object. Using it for explanation of the functioning of the eye, this is how the muscles reshape eye lens to focus images from different distances. Model of accommodation is shown on Picture 5. Note that the distance between the lens and the screen is kept constant.

Picture 5: Model of accommodation, featuring the eye, focused on the (a) near and (b) distant object.

a) b)



Conclusions

Human body is taught very thoroughly in primary, secondary and high school, but actual functioning of it remains a mystery, according to the students' answers to a simple questionnaire.
Optics is also taught from primary to the university level, but generalization of the principles or using them in a new content is still a goal to achieve. Experiments presented, hopefully, provide an interesting demonstration and a model to help students visualize the process of vision. On the other hand, it helps to show interdisciplinarity of science, its connection to everyday life and its role in meeting our needs.

References:

E. Hecht, Optics. Addison – Wesley, New York, 1998.
http://hyperphysics.phy-astr.gsu.edu.