Michael J. Ruiz, “Dioptres for a Myopic Eye from a Photo,” *Physics Education* **54**, 065010 (November 2019). The publication includes photos and video of three UNCA students (Meritt B. Tutwiler, Daniel S. Secor and Vladislav A. Rakhouski) from *PHYS 101 Light and Visual Phenomena* (Spring 2019) demonstrating the physics principles.

Dioptres for a Myopic Eye from a Photo

Michael J Ruiz

Department of Physics, University of North Carolina at Asheville, Asheville, North Carolina, 28804, United States of America

E-mail: ruiz@unca.edu

Abstract

This paper is inspired from a scene in the movie *Memento* (2000), where the eyeglass prescription for a myopic eye can be estimated since the virtual image of a distant wall seen through the lens and a nearby actor outside the view of the lens are located at the same distance. The estimate illustrates that there are times when the power of physics allows one to arrive at a sophisticated measured result with no equipment. This fascinating example also provides for a nice interdisciplinary connection between physics and medical optics. Due to copyright restrictions on incorporating a movie in class, teachers may use the author’s photo and video included here or have their students make similar media with their smartphones.

Background

The most prevalent eye disorders are refractory problems [1], difficulties where one cannot achieve a sharp image on the retina without eyeglasses. Most young students wearing glasses have myopia, also called nearsightedness, where glasses are needed to see the blackboard. Recently it has been reported that ‘short-sightedness is reaching epidemic proportions’ [2] and in ‘urban communities in Asia, the prevalence is greater than 80%’ [3]. Though genetic factors can play a role, the surging increase in myopia is due to ‘excessive environmental exposures such as large amounts of nearwork and insufficient time outdoors in bright light' [4]. 'Outdoor activity protects against childhood myopia' [5] in other words. Recent studies indicate that lack of exposure to brighter outdoor light levels rather than close work may be the most important cause for myopia in schools [2]. The widespread increase in myopia along with the current research to meet the social challenge to curtail its growth makes it very relevant for incorporation in introductory physics.

Myopia and introductory physics

Medical examples in physics are important for their interdisciplinary applications of physics and preparation for students pursuing careers in medicine. Many medical topics are suitable for introductory physics at the pre-university level [6]. An excellent example is the AQA A-level Year 2 text on medical physics, which includes a section on prescribing eyeglasses relevant to this paper [7].

The myopic eye has been shown by 'A-scan ultrasonography and other methods' to eventually become elongated [8]. Therefore, parallel rays refract too much and do not reach the retina as illustrated in the eye schematic of figure 1. The cornea and eye lens are represented in the simple eye of figure 1 by one net converging lens. The cornea is the outer surface of the eye where most refraction occurs. The eye lens is located a short distance inside the eye and changes shape to allow for seeing at different distances, a process called accommodation.

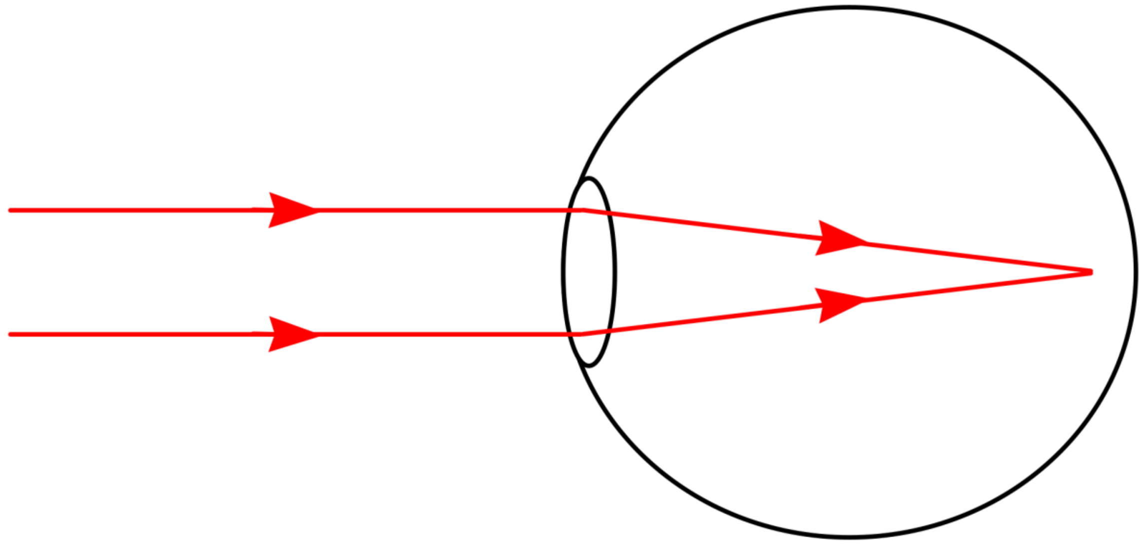


Figure 1. Eye schematic showing parallel rays focusing before reaching the retina. The cornea and eye lens are represented as a single effective lens.

When the normal eye focuses at infinity, the eye lens becomes flatter. The suspensory ligaments on its periphery pull outward due to the relaxing of the attached ciliary muscles. When the normal eye focuses close up, the ciliary muscles push in, the suspensory ligaments loosen, and the eye lens bulges increasing the refractory power of the eye. A student in grade school with normal vision can often see closer than the 25 cm standard for reading a book. As one ages, the range of accommodation lessens.

To the myopic eye distant objects appear blurred. A diverging lens can correct for myopia since parallel rays leaving the lens diverge before entering the eye. The over compensation of the myopic eye to converge the rays brings the diverging rays to the retina. Another way to think of the solution is that a virtual image of the distant object Is formed by the lens so that the image is close enough for the myopic eye to see. The diverging lens illustrated in figure 2 accomplishes this task. Note that the actual refraction at the lens takes place at the incoming air-glass and outgoing glass-air interfaces. Though the virtual image is small, the ray through the lens center is aligned with both the object tip and image tip. The brain interprets the arrow to be proportionally large and far away.

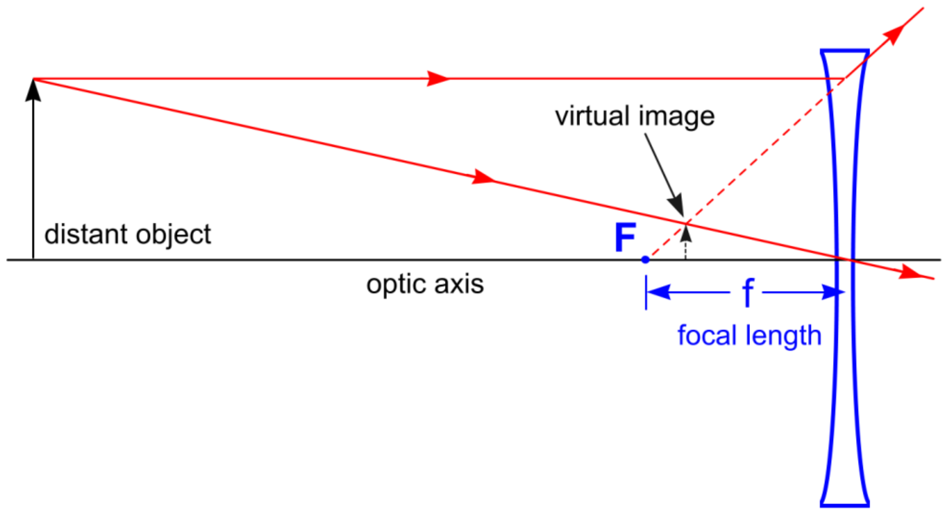


Figure 2. Diverging lens forming a virtual image of a distant object. For objects at infinity the images will be in the focal plane, at a distance f from the lens.

For the most distant objects (at infinity), the virtual images will be on the vertical plane at F. The point F is called the focus or focal point and the vertical plane at F is called the focal plane. In the case of a diverging lens, a minus sign is included to distinguish it from a converging lens. In the diverging lens F is a virtual focal point since parallel light entering the diverging lens appears to diverge from this point. In contrast, for a converging lens, the refracted light rays meet at the focal point and the focal length is taken to be positive.

The key idea in prescribing the correct focal length for the myopic eye is to choose the focal length to match the far point of the eye, i.e., the point beyond which objects start to get more and more blurry. In the medical field the prescriptions for lenses are given in dioptres. The dioptric value is the reciprocal of the focal length when the focal length is expressed in metres. Dioptres are preferable since dioptres add when two thin lenses are placed together and the dioptric value indicates the strength of the lens. Equation (1) gives formulas for calculating the strength or power of a lens in dioptres when the focal length is expressed in metres and centimetres.

$$P(\text{dioptres}) = \frac{1}{f\ (\text{in m})} = \frac{100}{f\ (\text{in cm})} \tag{1}$$

Figure 3 shows a scene where some of the light passes through the diverging lens, providing an actual example of figure 2. Note that the components of the virtual image are smaller compared to what is seen outside the eyeglasses. The virtual image is located fairly close to the glasses, as indicated by the ray diagram of figure 2. The power of the diverging lens in figure 3 is -5 dioptres with a corresponding focal length of -20 cm. Therefore, images of distant objects will be 20 cm from the lens. Figure 3 includes a hand at the left placed at 20 cm from the lens. The aim of this paper is for students to take photos similar to figure 3, including a subject outside the field of the eyeglasses in the same plane of the virtual image. The photo should have enough clues so that someone viewing the photo can estimate the distance from the lens to the virtual image. The next sections describe such photos in detail and how to use them in a class on lenses.

Figure 3. Eyeglasses where each lens is –5D. Distant images have corresponding virtual images in the plane at a distance of 20 cm from the lens, in which plane the left hand is also located.

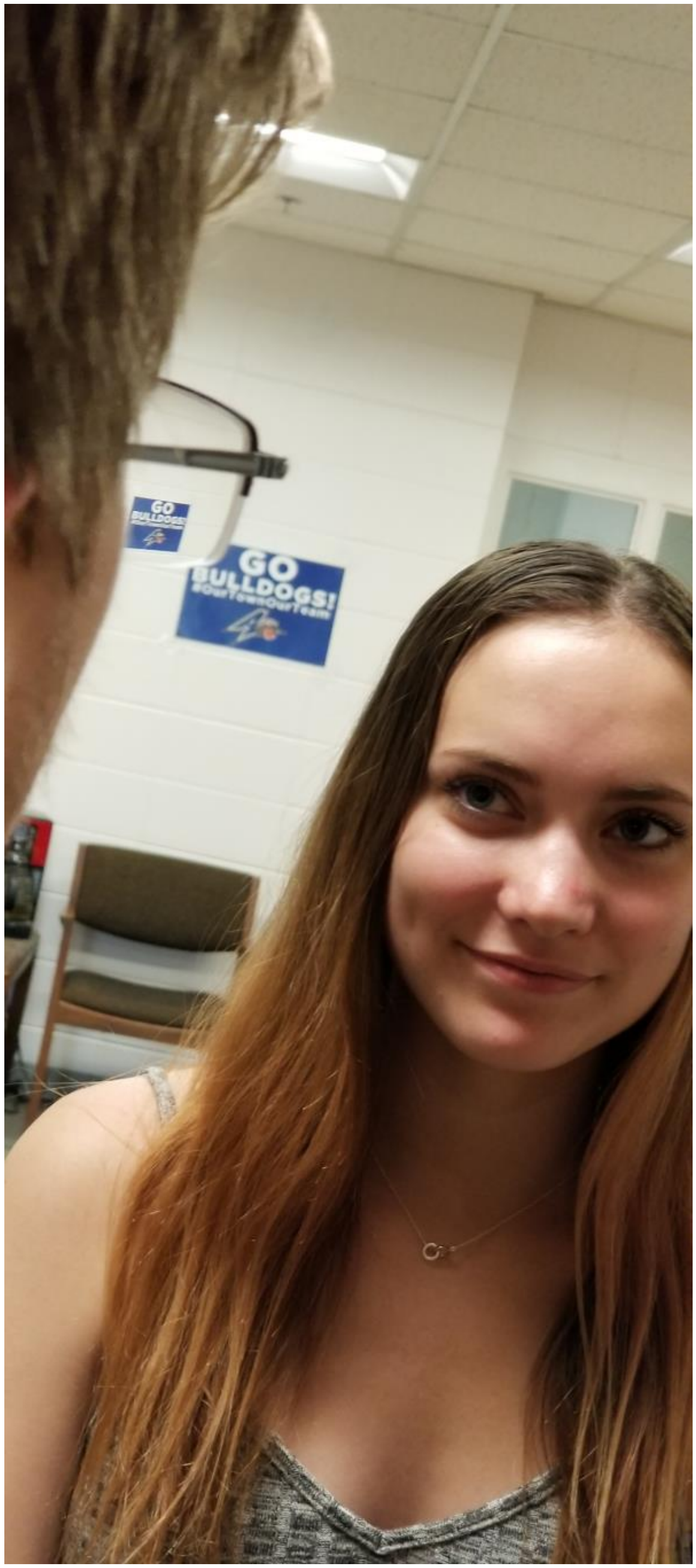
The movie *Memento* (2000)

The inspiration for this paper comes from the movie *Memento* (2000). I was watching this movie when a scene appeared with two of the actors, Guy Pearce and Joe Pantoliano having a conversation. The camera was focused on Guy Pearce with the back of Joe Pantoliano's head partially seen in the left of the scene. The camera captured the virtual image of tattoos from a distant wall through the eyeglasses Pantoliano was wearing. Meanwhile, the wall outside the field of the eyeglasses showed the tattoos as blurred. The effect was very aesthetic and interesting. I wondered if it was an optical accident that the cinematographer liked and kept shooting with the virtual images included.

Figure 4a shows a reproduction of the arrangement with two of my students, while a third student took the photograph. Figure 4b is a detail of figure 4a so that the sharp virtual image of the letters through the lens can be better compared to the out-of-focus image of the poster on the distant wall outside of the lens. In the next section I suggest how to use figure 4a in a classroom discussion so that students are led to make the remarkable discovery that the eyeglass prescription can be determined from the photo.

Due to copyright laws teachers can use photos and the video accompanying this paper rather than the film *Memento*. Be aware that the British Board of Film Classification (BBFC) rates the movie as ‘passed “15” for strong language and violence’ [9]. In the US the movie is ‘rated R for violence, language and some drug content’ [10]. If your students are underage, the images and video from this paper can be used without even mentioning the movie.

Figure 4a. Photo of two students having a conversation where the virtual image due of the poster on the distance wall is included.



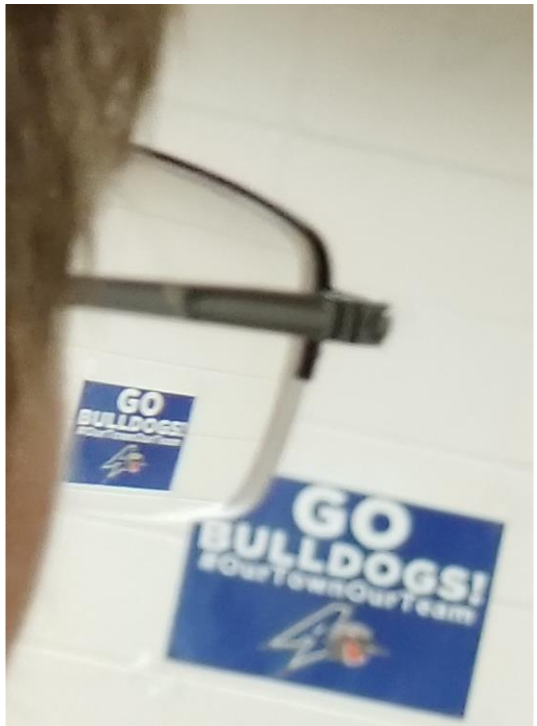


Figure 4b. Detail of figure 4a in order to better compare the sharpness of the virtual image to the blurred distant wall.

Classroom posed challenge

Most students wearing glasses in class will have myopia. In fact, some students first become aware of their myopia on discovering their difficulty seeing letters on the blackboard in class. During the lesson on lenses, I ask my students how does the ophthalmologist or optometrist determine a prescription. Students with glasses will remember sitting in a chair with a huge instrument brought to the their eyes with many lenses. The doctor then rotates combinations of lenses into place asking the patient if the letters on the chart are better or worse. In this way, an accurate prescription is arrived at.

Then, I draw their attention to figure 2 and explain that the focal length needs to be equal to the far point of the myopic eye so that it can see distant objects clearly. I ask a couple of nearsighted volunteers with strong glasses to come to the front of the class. I have them stand close to the computer screen on the desk at the front, take off their glasses, and give them a moment to adjust. Then I have each in turn cover one eye with a hand and look at the computer monitor as far away as possible where the computer text is still clear. When this distance is reached, another student can measure the distance from the computer monitor to the observing eye. It is not uncommon to find someone that cannot see clearly farther than 20 cm from the computer screen.

Now it is time for math. The 20 cm measured is the focal length labeled f in figure 2 and I remind them that they need to insert the minus sign for a diverging lens. I then ask them to use equation (1) to arrive at the prescription in dioptres. The power in dioptres is

$$P(\text{dioptres}) = \frac{100}{f \text{ (in cm)}} = \frac{100}{-20} = -5 \text{ dioptres} = -5\text{D}.$$

The strong eyeglasses of figure 3 seen earlier has a pair of –5D lenses. For students not so myopic, they can stand in the classroom as far back as one eye can clearly see text at the front of the class. A far point of 2 m gives a very weak prescription of –0.5D.

Of course the experimental method used by the eye doctor for the precise prescription is the gold standard. However, the physics demonstration with just the meter stick shows the power of physics in making an estimate of a prescription with no specialized equipment [11]. Now comes the magic. I ask the students if it is possible to estimate a prescription from a photo such as figure 4a using solely the photo as the only source of information. At first, this feat seems impossible. The subject wearing the glasses is not present in the room for us to make any measurements. We just have the photo.

If students need prodding, I point out that the virtual image of the letters on the wall poster is clear in the photo of figures 4a and 4b. Can the distance from the lens to the virtual image be determined? Since the wall is fairly far away, the virtual image should be close to the focal plane. If we know the focal length, we can find the prescription. Who is the photographer focusing on in the photo? The students will readily answer the lady. How far is she from the guy with whom she is having a private conversation?

To make the students feel more at ease, I remind them we are going for an estimate, so is the distance more like 25 cm, 50 cm, 75 cm, 100 cm, etc.? The estimate they will give is 50 cm, which leads to a prescription of –2D for the eyeglasses in figure 4a. For fun and to involve the students more, I sometimes ask two students to come up front and stand close facing in each other like the two people in the photo. I tell them the distance doesn't have to be exact. Just look at the photo and approximate things. Then I ask the class to give an estimate. Once again, 50 cm is the typical answer. Sometimes I ask a third student to come up and use a meter stick to measure the distance from the eyeglasses to the person facing the student with the glasses.

In summary, the prescription discussion started with expensive equipment in the doctor's office. Then, the power of physics led to experimental measurements in class with a meter stick, where individuals stood from a computer or poster at the front of class to determine far points. Finally, a prescription was estimated from just a photo! For this last case the students will be able to go through the reasoning mentally as the math requires merely the calculation $-100/50 = -2$D.

Students making their own photos and videos

I include a video [12] of my students making photos of two students talking similar to figure 4a. One difficulty is immediately encountered with smartphone cameras. These built-in cameras have small apertures which tend to make things in tolerable focus over larger distances compared to traditional cameras. In photography, we say that the depth of field is great. The smaller the opening, the greater the depth of field until the opening is so small that diffraction appears. The depth of field for a pinhole camera is infinite [13].

So my students went outside where a large banner was much farther away in order to get better sharpness contrast between the virtual image seen through the lens and the distant object outside the lens. See figure 5a for such an outdoor photo and figure 5b for detail of the hanging banner with letters. The eyeglasses have prescription of –2D for each lens. For the demonstration I purchased at an extremely cheap price a pair of eyeglasses online with a prescription of –2D for each eye. I also purchased the –5D glasses seen in figure 3.

My student Vlad taught me that for best smartphone result the photographer needs to tap on the face of the subject so that camera focuses more precisely there, where the virtual image is also located by arrangement. If a student has a traditional camera with manual focus and controls, the student can choose the largest opening possible so that the depth of field is poorest. Then, manually focus on the subject and virtual image for the photo and choose the appropriate shutter speed. The contrast between the focused virtual image and distant object will be more much pronounced as it is in the movie *Memento*. However, the advantage of the smartphone is that students will be able to jump in and partake in the project.

Students with myopia will be in the class. The students can use their creativity in setting up scenes so that the camera captures the virtual image and an interesting subject at that same distance. They can then post their photos digitally and share them with the rest of the class. They can then see if their classmates can estimate the prescription in each case. If the prescription is unknown before the photo is taken, the student team can set up the arrangement of figure 3 and measure the distance from the lens to the left hand in figure 3 to arrive at the focal length. Then they can proceed to compose a photo such as figure 4a or 5a. Or they might come up with alternative creative photo compositions.

Figure 5a. Photo similar to figure 4a with the poster farther away so that the far sign is relatively more blurred.

Figure 5b. Detail of figure 5a showing virtual image in focus and distant flag blurred as the camera is focused on the virtual image.

Conclusion

This paper describes a classroom demonstration where students can prepare photos from which their classmates can be challenged to estimate the prescription of eyeglasses for myopic eyes. The trick is to take a photo which includes the virtual image formed by at least one of the lenses through the glasses as well as an interesting subject (person or object) located at the same distance as the virtual image. Students just need a smartphone and two partners as shown in our video [12]. The reader can download high resolution versions of our figures for classroom use [12]. The students can also use their imagination to set up additional and unique photo compositions achieving similar results. Therefore, the physics project also incorporates an valuable artistic component.

Acknowledgements

I would like to thank three of my students from my Spring 2019 class *PHYS 101 Light and Visual Phenomena*: Meritt B Tutwiler, Daniel S. Secor and photographer/videographer Vladislav A Rakhouski. The author has confirmed that any identifiable participants in this study have given their consent for publication.

References

[1] Hashemi H et al 2018 Global and regional estimates of prevalence of refractive errors: Systematic review and meta-analysis *J. Curr. Ophthalmol.* **30** 3-22

[2] Dolgin E 2015 The myopia boom *Nature* **519** 276-8

[3] Cooper J and Tkatchenko A V 2018 A review of current concepts of the etiology and treatment of myopia *Eye Contact Lens* **44** 231-47

[4] Morgan I G and Rose K A 2019 Myopia: is the nature-nurture debate finally over? *Clin. Exp. Optom.* **102** 3-17

[5] Zadnik K and Mutti D O 2019 Outdoor activity protects against childhood myopia – Let the sun shine in JAMA *Pediatr.* **173** 415-6

[6] Gibson A P, Cook E, and Newing A 2006 Teaching medical physics *Phys. Educ.* **41** 301-6

[7] Bishop C 2016 *AQA A-level Physics Year 2 Student Book, Book* 2 (*Collins AQA A-level Science*) London: HarperCollins) p 6-12

[8] Rhem D S 2005 *Petition to the US Food and Drug Administration* (Ligonier, Pennsylvania, USA: International Myopia Prevention Assn.)

[9] *Memento (2000)* 2019 British Board of Film Classification (BBFC): View what's right for you (London: BBFC) https://bbfc.co.uk/releases/memento-2000 (accessed 23 June 2019)

[10] *Memento (2000) Parents Guide* 2019 Internet Movie Database (IMDb) (USA: Amazon) https://www.imdb.com/title/tt0209144/parentalguide

[11] Ruiz M J 2005 Prescribing eyeglasses for myopia and hyperopia *Phys. Teach.* **43** 88-9

[12] Ruiz M J 2019 *Video: Myopia* (http://mjtruiz.com/ped/myopia/)

[13] Morales G, Perkins J, Pomfrey H, and Ruiz M J 2019 Accurate pinhole camera apertures using insect pins," *Phys. Educ.* **54**, 025002 (6pp).

Michael J Ruiz is professor of physics at the University of North Carolina at Asheville (UNCA), USA. He received his PhD in theoretical physics from the University of Maryland, USA. His innovative courses with a strong online component aimed at general students have been featured on CNN.