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A lens to demonstrate accommodation in the focusing of the human eye – Low cost version

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Abstract

The human eye changes shape (accommodates) in order to focus on objects which are located at different distances from it. To mimic this change of shape and help students understand the optics of accommodation, we have developed a low-cost, robust lens which has a variable focal length.

Construction of Apparatus:

The apparatus is a variation on two others which can be used to demonstrate accommodation. One is a component in a very expensive model of the eye¹. The second is inexpensive and made from a plastic Petri dish and a condom, but is not as robust as our version².

Our variable focus lens is made entirely from materials which can be purchased from hardware or home improvement stores. In our attempt to build a model of the eye which is able to model nearsightedness and farsightedness as well as the accommodation abilities of the eye, we found it possible to construct an affordable accommodating lens from equipment that is easy to both obtain and work with.

The following is a description of the accommodating lens that we found most convenient. In particular, the sizes listed in parenthesis are the ones that we chose based on the equipment that was already in use at our institution – these sizes can of course be altered to fit other needs.

Materials:

- PVC pipe (1inch outer diameter) available from any home improvement store

- For example, from McMaster Carr, item #48925K93 (\$4.46 for 5' piece)
- PVC couplings, 1" diameter available from any home improvement store
 - For example, from McMaster Carr, item #4880K73 (\$0.49 each, need 1 for each lens)
- Syringes (10-29 mL)
 - Usually less than \$1.00 each.
- Transparent silicone rubber sheets, (approximately .02" thickness)
 - For example, from McMaster Carr in 12"x12" sheets, item # 86915K12 (\$17.78 each)
- Light source. We use a bicycle taillight (Cost range \$10-\$25). By covering one of the LEDs in a light with 4-5 LEDs the students can easily observe the inversion of the image.

The total cost per lens is dependent on how many lenses one wishes to construct. For example, \$4 worth of 1 inch PVC contains enough material to make about 100 lenses. However, we doubt that most teachers will want to construct that many. If you made 10 lenses from the materials listed above, the cost per lens would be less than \$4.00. Thus, the total cost of the apparatus is about \$25.

Procedure

1. Cut the necessary pieces:
 - Cut PVC pipe into sections about 0.6 inches wide. This width allows enough room for the syringe and the coupling.
 - Next, cut the PVC couplings into rings, about 1/8 inches wide. We were able to get 1-2 rings from each side of the coupling (after this, the tapered nature of the couplings restricted our ability to work with them).
 - Cut the film into rectangles that are about 1/8 to 1/4 inches larger than the PVC rings in all directions.
2. Drill a hole in the center of each PVC section – the diameter of the hole should be chosen such that the tip of the syringe will fit very snugly into the hole.

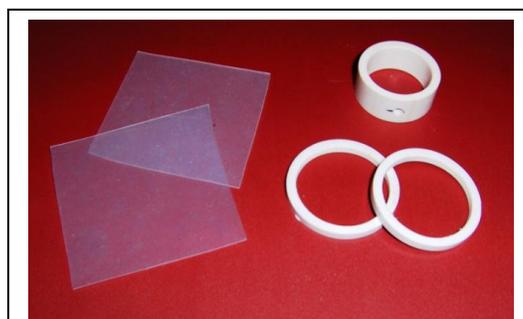


Figure 1: The components of the accommodating lens

3. Assemble the lens:
 - Place a piece of film over top of one side of the PVC section, and use the PVC ring to compression-fit the film in place.
 - Repeat on the other side.

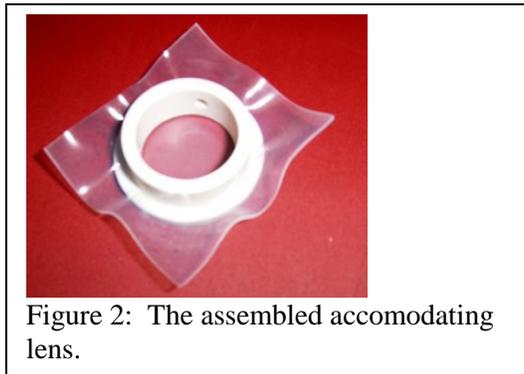


Figure 2: The assembled accomodating lens.

4. Fill the syringe with water, and then press firmly into the hole.
 - For the first filling: slowly add water, remove the syringe from the hole and squeeze the lens to push the air out through the hole. Doing this repeatedly will allow the lens to fill with water and minimize the air bubbles.
 - The lenses work best when the syringe is held upside-down so that minimal air is added.

Use of Apparatus:

Accommodation

For us to be able to see clearly, visible light must pass through the optics of the eye and come to a focus on the retina. Students learn from using ordinary lenses that a lens with a fixed focal point cannot focus objects which are located at a variety of distances to the same image distance. Because the lens-retina distance is fixed, the focal length of the lens must change for us to see clearly objects at a variety of distances. This change is accomplished by the ciliary muscles changing the curvatures of the eye lens. This process is called accommodation. See Figure 3. Creating an analogy of the ciliary muscles would be extremely difficult. However, creating a similar process that shows how accommodation can occur is relatively easy.

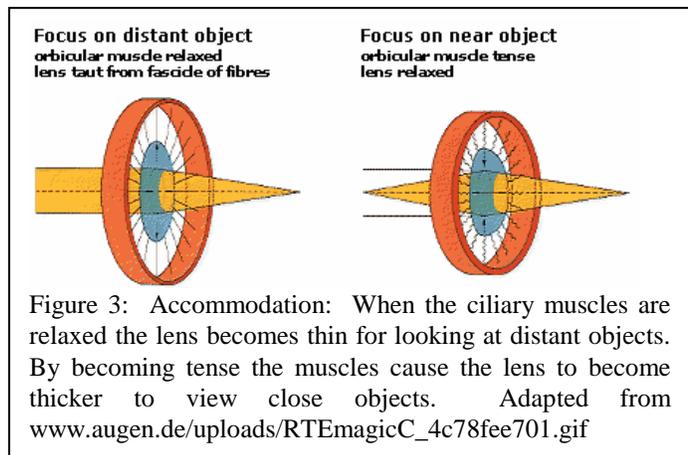


Figure 3: Accommodation: When the ciliary muscles are relaxed the lens becomes thin for looking at distant objects. By becoming tense the muscles cause the lens to become thicker to view close objects. Adapted from www.augen.de/uploads/RTEmagicC_4c78fee701.gif

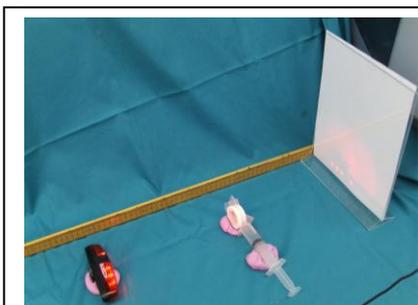


Figure 4: An overview of the apparatus. Play-Doh is used to hold the components in place



Figure 6: Now the image is in focus.



Figure 5: The image is out of focus.

Students place a screen at a fixed distance from the lens, usually about 30 centimeters. This distance represents the distance between the eye lens and the retina. Thus, it cannot be changed during the rest of the experiment.

A light source is placed at different distances from the accommodating lens. At each distance the students use the syringe to adjust the amount of water in the lens until the image is focused on the screen. Data is taken on the location and the thickness of the lens. We also ask them to record qualitative information about the curvature of the lens for each location of the object. Our students have found that they can bring the object into focus from a few centimeters in front of the lens to about four meters.

Accommodation and Vision Defects

Accommodation also plays a role in vision defects and can help us partially adjust to abnormal vision. To enable students to discover how this attribute improves our vision, we have them set up a situation where the object is in focus on the “retina.” Then move the retina slightly toward the eye lens (farsighted eye). Then the students can change the amount of water in the lens to bring the object back into focus. By moving the “retina” even closer, they can repeat the experiment. However, they will reach a location for the retina where the accommodating lens can no longer focus the object. Thus, the defect is severe enough for the eye to need corrective lens. A similar experiment can be completed with the retina moving away from the eye lens (nearsighted eye).

Figures 7-10 show the type of diagrams that students should draw as they collect data for the experiment. Using these diagrams and formal ray diagrams, the students will be able to describe how the changes in the lens shape changes the focal length of the lens. From the changes in the focal length they can describe why the in-focus image falls on the retina for the correct focal length but is blurry if the eye lens as not properly accommodated.

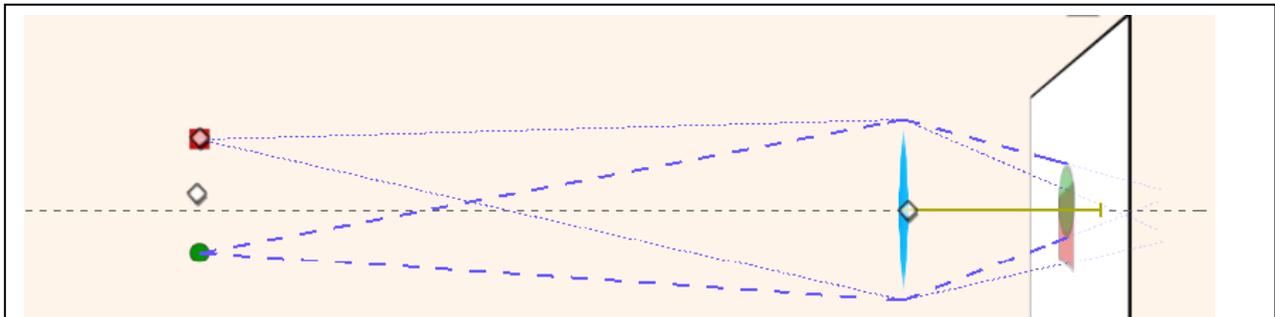


Figure 7: The lens is too thin to focus the object on the screen. Thus, the focal length is too long. This situation represents an eye lens that has not accommodated properly. The vision is blurred.

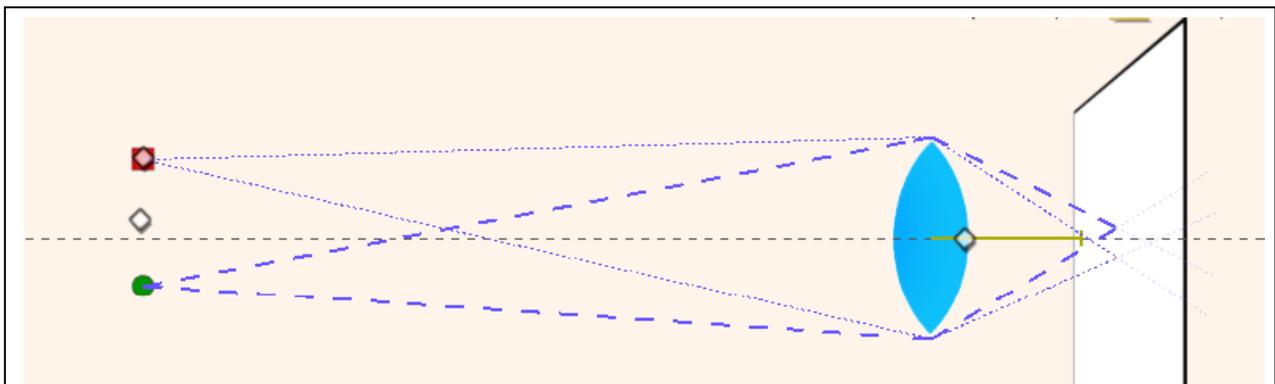


Figure 8: The location of the object and screen are the same as in Figure 7. However, this lens is thicker. Thus, it has a shorter focal point, and the image is in focus on the screen. The vision of this person is clear.

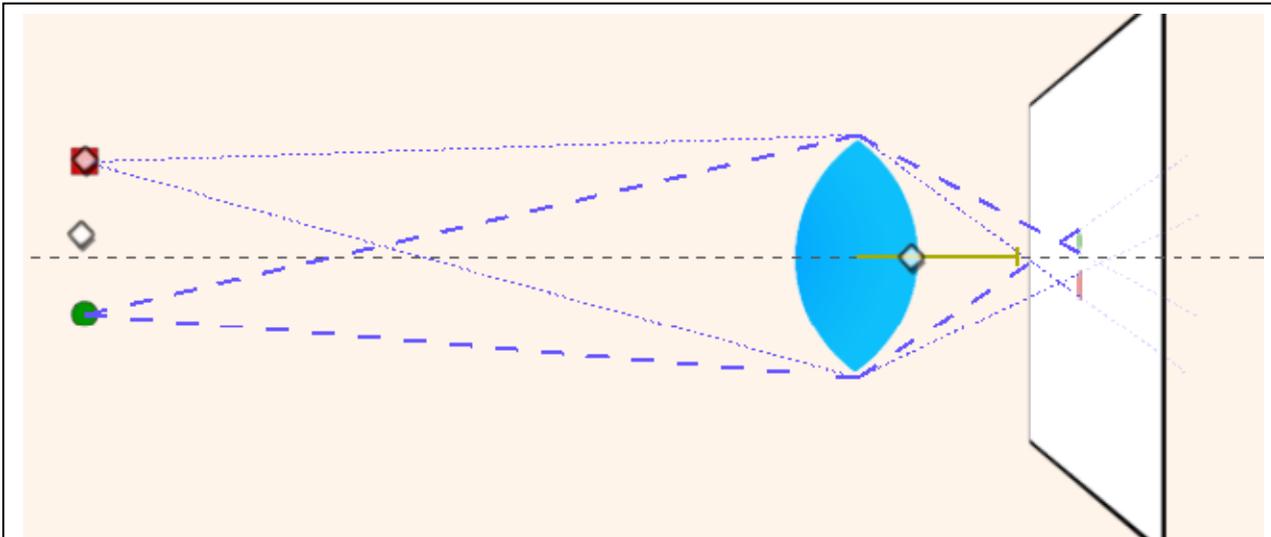


Figure 9: The lens of the eye is thick and has a short focal length. Thus, the image would be in focus in front of the screen. Vision is blurred.

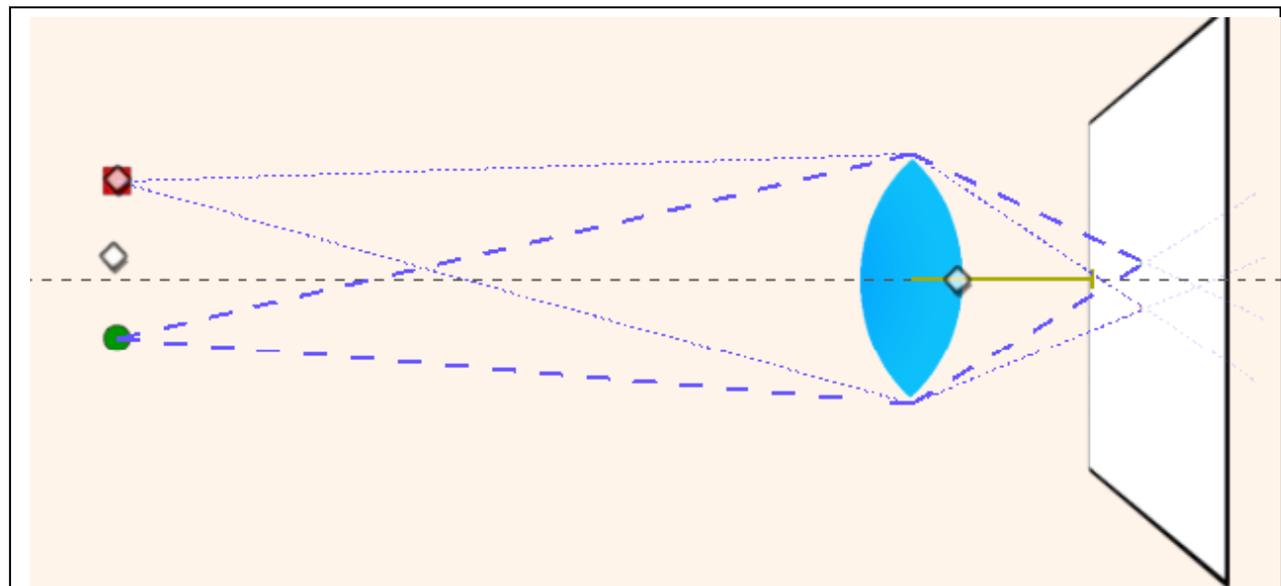


Figure 10: The object and screen are in the same locations as Figure 9. However, the lens is thinner and has a longer focal length than the lens in Figure 9. The image focuses on the screen/retina and the vision is clear.

Caveat

These experiments are very visual and easy for the students to see how the changes in the lens shape leads to the object being focused. This visual nature is also drawback. Students could come away from these experiments believing that the human eye lens changes shape by having a liquid move in or out of it. Thus, we repeat frequently that our accommodating lens is a model and not the real thing. This approach, while far from ideal, seems to have helped minimize the introduction of this possible misconception.

Acknowledgements

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References

1. ~\$400 from Universal Medical, Inc. <http://www.universalmedicalinc.com/Eye-Models-s/55.htm?gclid=CMfM8J7UjqICFciA5QodyUGAVQ>.
2. G. Colicchia, H. Wiesner, C. Waltner, and D. Zollman, "A Model of the Human Eye" *Phys. Teach.* **46** 528 (2008).