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Question 1: Losing Weight; Question 2: Artificial Moon

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hand. A third student can record the measurement for the others. Another reason is that multiple measurements allow the students to calculate an average focal length for each lens, which helps them to achieve a more precise result. Second, it is important to emphasize what we mean by "blur" in this instance. An image seen through the lens can look blurry—i.e., not perfectly focused—even if not exactly at the focal point. From experience, students have a tendency to overestimate the distance from the eye to the focal point, so it is important to give students some extra instruction and attention when performing this task.

Once student teams have determined focal lengths for both lenses, they can "construct" their telescopes. We are not worried about placing the lenses at opposite ends of a tube; instead, simply have each student take turns holding one lens next to an eye and moving the other lens back and forth while looking for a clear image in the middle of the far lens. When this happens, we have our telescope. As an added benefit, students need to determine which lens is which—that is, which lens should be held close to the eye and which should be held far away. In astronomy, the lens furthest from the eye will have the longer focal length and is called the *objective* and the lens next to the eye is the *eyepiece*. The focal lengths can thus be abbreviated as f_o and f_e, respectively.

As discussed earlier, the sum of the focal lengths should be the same as the distance between the lenses. In this type of mini-experiment, we shouldn't expect to achieve a great deal of precision; nevertheless, with careful work on the part of the students, one can expect to get within 10% difference between the sum of focal lengths and the measured distance between the lenses.

Another property of interest for a telescope is its *magnification*. In optics, magnification is simply the ratio of the size of the image compared to the size of the object. Since one of the benefits of using a telescope in the first place is to make an image larger, we want our students to construct a telescope in such a way as to guarantee a larger image.

The magnification m of our telescope is given by

$$m = -\frac{f_o}{f_e}. \qquad (2)$$

The negative sign references the fact that the image will appear upside down through our refracting telescope. Galileo's first telescope reportedly had a magnification of +3; an interesting question for the students is to have them compare their telescope to that of Galileo.

Depending on the needs of your class and time available, you can expand this activity to include questions regarding light-gathering power, resolution, and the proper ways to describe images. We have made a sample activity available.[2] Enjoy your new telescopes, and clear skies!

Reference

1. This configuration of two lenses is called a refracting telescope (or refractor), since it only uses the refractive properties of lenses. The other major type of telescope, the reflector, uses mirrors and was invented many decades later by Isaac Newton. A reflector is more complicated than a refractor, and we are interested in simplicity in this activity.
2. View the activity at *TPT Online*, http://dx.doi.org/10.1119/1.5084934, under the Supplemental tab.

Fermi Questions

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Question 1: Losing weight

How much mass does the Sun lose over its lifetime? *(Thanks to Dan Fehlauer, Dexter Southfield HS, for suggesting the question.)*

Question 2: Artificial moon

China is planning to launch an artificial moon to help illuminate a city at night. How big a satellite would be needed to provide as much illumination as a full moon?

Look for the answers online at *tpt.aapt.org*

Question suggestions are always welcome!

For more Fermi questions and answers, see *Guesstimation 2.0: Solving Today's Problems on the Back of a Napkin,* by Lawrence Weinstein (Princeton University Press, 2012).

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