

Water-Drop Projector

Gorazd Planinsic, Department of Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia; gorazd.planinsic@fiz.uni-lj.si

Due to a growing interest in biology among science students, using demonstration experiments in physics classes that involve observations of biological material or that relate to plant, animal, or human physiology can often raise student motivation. The experiment described below involves observation of microorganisms in a drop of pond water. An explanation of the image formation in the paraxial region is then given using geometrical optics.

Beginning with the invention of the first microscope, humans have been fascinated by the observation of microscopic life. In his spare time, Dutch draper Antoni van Leeuwenhoek (1632-1723) made his own single-lens microscope using a small glass sphere. Keeping de-

tailed records of his observations, he made the first drawing of a bacterium in 1683. Articles describing construction of a simple variation of Leeuwenhoek's microscope (glass tubing microscope) have appeared previously in *TPT*.¹ However, it is easier still to build a single-lens microscope by using a drop of clear water instead of a glass lens. The small water drop works as a spherical lens with a large magnifying power.

Experiment

To collect your sample, fill a syringe with water from a pond or large puddle with a lot of decaying plants. If you live at the coast, use seawater. Try to catch some very small animals (0.2 mm to 0.5 mm) that move around in the water. Many of them are found close to the bottom of the pond.

Fix the syringe on a holder (Lego blocks or a piece of wood works well) using adhesive tape as shown in Fig. 1.

For a light source, fix a laser pointer on a vertical positioner. An empty stick-deodorant container will do, as shown in Fig. 1. To create your lens, carefully push the syringe piston until a water drop (about 2 mm in diameter) is formed at the end of the nozzle.

Observation

Place the syringe holder on a table about two meters away from a screen or white wall. Switch on the laser pointer and adjust the beam to point exactly through the middle of the water drop and perpendicular to the screen. For fine horizontal adjustment of the laser pointer, move the deodorant container, and for vertical adjustment use the built-in turn screw. With the right adjustment of the laser, a bright spot extends into a large round image on the screen about 2 m



Fig. 1. Water-drop projector: experiment setup.

Author: are you certain of the taxonomic identity of this animal? If not, then perhaps "Cyclops (*Cyclops species*)" would be a more appropriate caption for first photo below.

in diameter. Now, if your pond water is rich enough with little animals, you should see their magnified shadow images floating and moving around on the screen. Small single-cell animals like *paramecium* appear as dark spots surrounded with interference fringe contours. Some of them exhibit movements, but no detailed structure can be recognized. Larger animals such as mosquito larva (*Anopheles species*), cyclops (*Cyclops strenuus*), or water fleas (*Daphnia species*) appear like real monsters on the screen (see Fig. 2). Here you can clearly identify individual parts of their bodies and follow their movements. In our case the images were projected on the white wall and photographs were obtained with a digital camera (Kodak DC260). You may at first see nothing but the dark floating spots surrounded by a few concentric circles caused by light diffraction on small parts of decaying plants and single-cell protozoa. Be patient. The light attracts the little animals (a green laser works best), and after some time they swim down to the syringe nozzle and into the water drop. You can also give them a little help by dripping a few drops from the syringe.

How the Water-Drop Projector Works

The drop at the end of the syringe, though not a perfect sphere, can be treated as a small spherical lens. The light beam that falls on the drop refracts both times as it passes through the water-air interface. Let's follow the path of the ray that enters the water drop just above an object that floats in the water drop at a small distance x from the geometrical axis (Fig. 3). The ray will refract twice and reach the screen at the distance y below the geometrical axis. The distance y is determined by the distance from the drop to the screen d and the angle δ , which can be calculated using simple geometry:

$$\delta = \alpha - \angle RST$$

$$\angle RST = 2\beta - \alpha$$

$$\delta = 2(\alpha - \beta).$$

Using Snell's law,

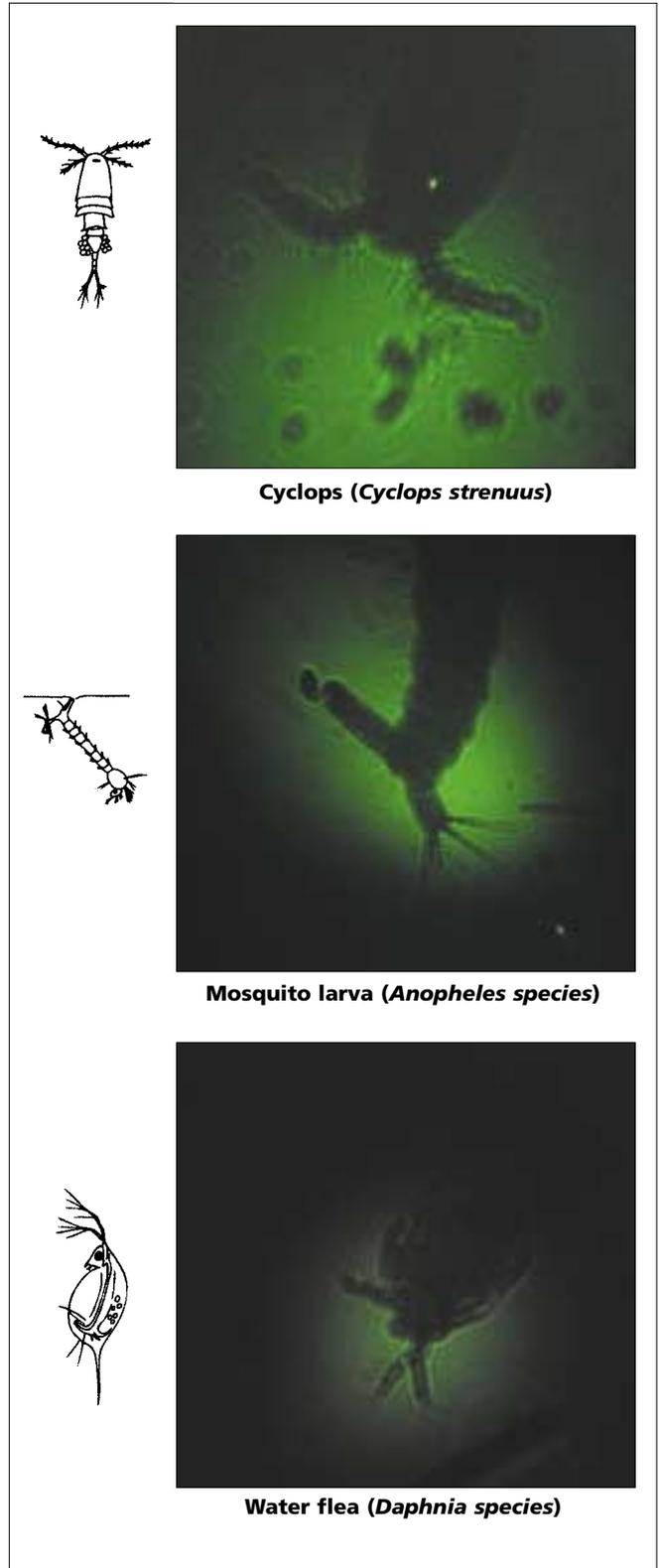


Fig. 2. Photographs of projected images. The actual size of each projected image is about 1 m x 1 m.

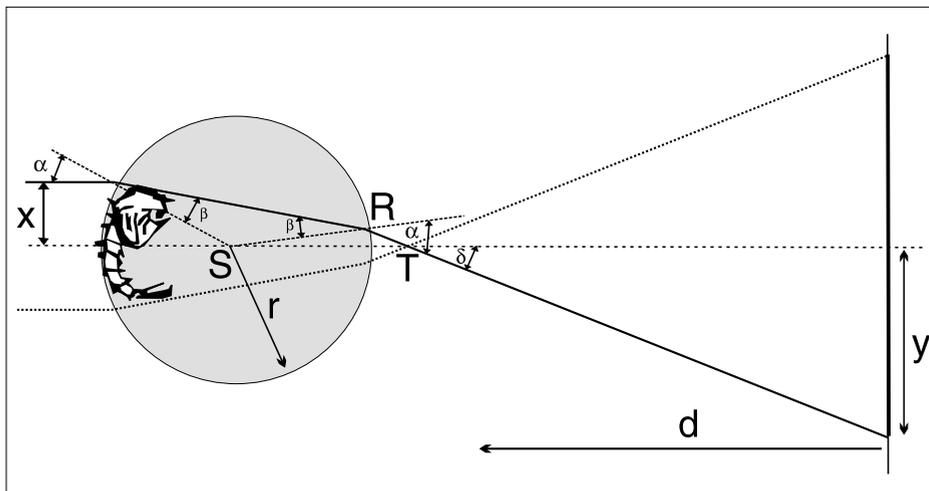


Fig. 3. Optics of the water-drop projector.

$$\frac{\sin \alpha}{\sin \beta} = \frac{n}{n_0}$$

(where for the water and air $n = 1.33$ and $n_0 = 1.0$, respectively), and with $\sin \alpha = x/r$, the angle δ is given by the equation:

$$\delta = 2\left(\arcsin \frac{x}{r} - \arcsin \frac{x}{nr}\right).$$

For the rays close to the geometrical axes (paraxial region), all the angles in the calculation above are very small; therefore, the expression for δ can be simplified using the approximation $\arcsin(z) \approx z$:

$$\delta = 2 \frac{x}{r} \left(1 - \frac{1}{n}\right).$$

The projected image on the screen is a magnified shadow of the object (animal) with magnification equal to

$$M = \frac{y}{x} = \frac{d \tan \delta}{x} \approx 2 \frac{d}{r} \left(1 - \frac{1}{n}\right),$$

where the approximation ($\tan \delta \approx \delta$) is valid in the paraxial region. For the water drop 2 mm in diameter, the shadow image on the screen 2 m from the setup is about 1000 times larger than the object. Note that in derivation we assumed the object floats on the laser side of the drop. It can be seen from Fig. 1 that the same shadow

height can be produced by a smaller object placed on the screen side of the drop (or anywhere in between). Clearly the magnification is largest for the objects that are floating in the screen side of the drop. In this case

$$M_{\max} = \frac{d}{2r} \frac{n}{2-n}$$

in the paraxial region. For the parameters as given above, the magnification factor is 1985.

The results show that in the paraxial region, the magnification depends on the position of the object along the geometrical axis but not on the object's distance from the axis. However, if the size of the object is comparable to the size of the drop or the object lies away from the geometrical axis, the angles α , β , and δ are not small any more. In this case, the magnification is expressed using the exact expression for the angle δ :

$$M = \frac{d}{r} \left[\frac{1}{u} \tan \left(2 \left(\arcsin u - \arcsin \frac{u}{n} \right) \right) \right],$$

where the distance of the incident ray from the geometrical axis is measured in the units of water drop radius ($u = x/r$) and can have any value between 0 and 1. The magnification as the function of parameter u is shown in Fig. 4 with the set of parameters given earlier. We can deduce from the graph that the magnification is reasonably constant within the region about half radius from the geometrical axis. This gives us a hint about the size of the drop for the given laser-beam diameter if we want to produce nondistorted shadow images.

The preceding derivation is based on the assumption that the water drop is a perfect sphere. Though the bottom part of the drop is spherical to a good approximation, the upper part (where the drop issues from the nozzle) is seriously distorted. The light passing through this irregularly curved surface causes a variety of patterns that disturb our observation but are interesting sub-

jects to explore themselves.² However, there are other ways to make a water drop lens that is closer to a sphere than the one we suggest. For example, wrap a copper wire (thickness of 0.2 mm or so) to make a small ring, then touch the ring with the water drop hanging from the syringe. The surface tension will make the drop jump onto the ring, where it will stay and form an almost perfect sphere. Or simply touch the drop from the syringe with a microscope glass plate and you'll get a nice plan-concave lens. These alternatives can be used to observe the small animals in the pond water, and the observed shadow images may be even better than those obtained with the hanging water drop method. But the advantage of this method is the simple construction and the fact that you can have many animals inside the syringe. The little animals attracted by the light swim down into the drop by themselves. With the other methods, getting the animals into the drop may be difficult, and the observation time is limited by the evaporation of the drop.

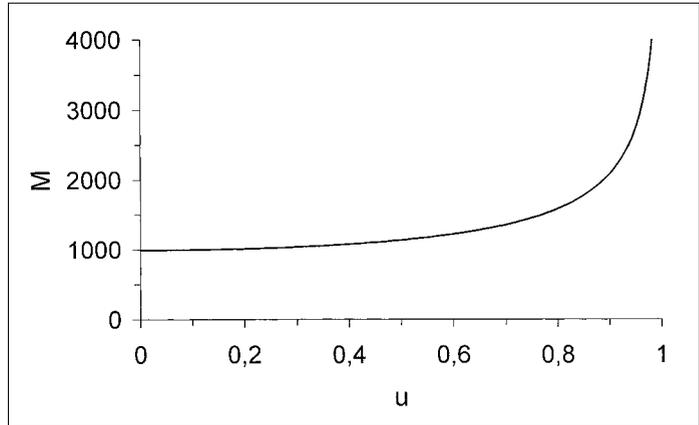


Fig. 4. Water-drop magnification as the function of distance from the optical axis.

References

1. Wayne O. Williams, "Glass tubing microscope," *Phys. Teach.* **17**, 204 (1979).
2. J. Walker, "A drop of water becomes a gateway into the world of catastrophe optics," *Sci. Am.* **120** (1989).